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AN

INTRODUCTION

TO

NATURAL PHILOSOPHY.

VOL. I.

AN

INTRODUCTION

TO

NATURAL PHILOSOPHY.

ILLUSTRATED WITH COPPER PLATES.

By WILLIAM NICHOLSON.

Non enim me cuiquam mancipavi, nullius nomen fero: multum magnorum virorum judicio credo, aliquid et meo vindico. Nam illi quoque, non inventa, sed quaerenda, nobis reliquerunt. SENECA.

IN TWO VOLUMES.

VOL. I.

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MDCCLXXXII.

TO

Sir JOSEPH BANKS, Bart.
P. R. S.

SIR,

GRATITUDE and reſpect are due, from every individual in ſociety, to him who promotes its real intereſt, by extending the bounds of knowledge. All Europe is acquainted with the exertions you have made for its advancement: permit me to join the voice of nations, by expreſſing the ſenſe I entertain of them. For this purpoſe, I take the liberty of dedicating the following treatiſe to the preſident of that reſpectable body of men, among whom the true philoſophy had its origin, and to whom it owes moſt of its improvements.

I am, with due reſpect,

SIR,

Your moſt obedient

humble ſervant,

LONDON,
Feb. 28, 1782.

W. NICHOLSON.

P R E F A C E.

THE advantages derived from the ſcience of Natural Philoſophy are ſo great, and ſo univerſally acknowledged, that an enumeration of them would be unneceſſary, if it did not ſerve to enliven and direct that ſpirit of enquiry which is natural to youthful minds, and to awaken thoſe, who from a want of reflection, are not inclined to look into the cauſes of things. We are apt to regard objects to which we have long been familiarized, with languor and indifference; and we now behold effects, without even the emotion of curioſity, which, in leſs enlightened ages, would have been thought miraculous.

Man, in a rude and ſavage ſtate, with a precarious ſubſiſtence, expoſed to the inclemencies of the ſeaſons, and the fury of wild beaſts, is an object of pity, when compared to man enlightened and aſſiſted by philoſophy. Ignorant of architecture, of agriculture, of commerce, and of all the numerous arts which depend upon the mechanic powers, he exiſts in the deſart, comfortleſs and unſocial, little ſuperior in enjoyment to the lion or the tyger, but much their inferior in ſtrength and ſafety. If it be true, that man ever exiſted in this ſtate, it could not have laſted long: the exertion of his mental ſtrength muſt have given riſe to the arts. Aided by theſe, the wilderneſs becomes a garden, embelliſhed with temples, palaces, and

populous cities; and he beholds himſelf removed to an immenſe diſtance from the animals, to which in his original ignorance he ſeemed nearly allied.

The ſciences beſtow that leiſure and independance which have enabled ſuperior minds to form laws, and to eſtabliſh the rights of mankind, by mutual compact between the powerful and the weak. By this leiſure it is, that ingenious and ſpeculative men have collected maſſes of knowledge, which induce us to regard the powers of the human mind with aſtoniſhment. Hence we poſſeſs the admirable ſcience of Aſtronomy. A ſcience founded on the moſt accurate and long-continued obſervations, and ſyſtematized by the pureſt mathematical reaſoning; but at the ſame time ſo remote from vulgar apprehenſion, that its daily and important uſes and predictions are hardly ſufficient to prevent its being regarded by the ignorant as a chimera!

The other departments of Natural Philoſophy are not leſs replete with wonders. How great would have been the ſurpriſe of the antients, could they have foreknown the effects which are produced by the reflection and refraction of light? By a ſkilful management of theſe properties, teleſcopes, and various optical inſtruments are conſtructed. Objects, too remote to be perceived by the naked eye, are enlarged and rendered viſible. The ſatellites of Jupiter and Saturn, the mountains and cavities in the Moon, and the changes which take place on the Sun's diſc, are thus diſcovered, and afford matter for admiration and enquiry. Neither is this delightful ſcience of Optics

confined

confined to the contemplation of diſtant objects. Minute animals, the veſſels of plants, and, in ſhort, a new world in miniature is diſcloſed to our view by the microſcope, and an inexhauſtible fund of rational entertainment and knowledge is brought within the ſphere of our ſenſes.

Every one is acquainted with the benefits derived from the ſcience of Hydroſtatics, to which we are indebted for many uſeful inventions. Among theſe are wind and water-mills, pumps, fire-engines, ſteam-engines, &c. &c.

Chemiſtry is productive of great and ſingular advantages to ſociety. Metallurgy, in its utmoſt extent, the arts of making glaſs and pottery, of dying, and many others, together with a very conſiderable part of the materia medica, are dependant on this branch of philoſophy. The vaſt importance of metallurgy may be rendered obvious from the ſingle conſideration of the many uſes to which iron is applied. Without this metal we ſhould be almoſt totally incapable of making any utenſil or inſtrument. It is difficult to recollect any production of art in the formation of which iron is not made uſe of: and the very exiſtence of naval commerce depends on its magnetical property.

Philoſophy is not therefore a dry ſtudy, but a purſuit of the higheſt utility and entertainment. Thoſe who cultivate the ſciences know that they naturally produce a ſincere and diſintereſted love of truth. An enlarged view of things deſtroys the effects of prejudice, inſpires the propereſt ideas of the great original cauſe, and promotes a deteſ-

tation of every thing that is mean or bafe. And if there be a pleafure in attending to objects which fill the mind by their immenfity, and delight the imagination by the continual difcovery of new and fublime analogies, it is not to be wondered that philofophers purfue their ftudies with a degree of attention and ardor which is not found in any other fet of men.

The order of arrangement in the prefent work is fuch as was fuggefted by the fubjects themfelves. After a curfory enumeration of the general properties of matter, Motion is principally attended to, being that affection of matter by which all changes are brought about. Mechanics and aftronomy naturally follow; and are fucceeded by an elucidation of the properties and motion of Light. The more complex motions of Fluids and the atmofpheric phenomena are next confidered. Thus far it will be obferved, that the work treats of fuch general effects as arife from the motions of bodies, without any particular refpect to thofe fpecific properties which diftinguifh them into various claffes. The remaining part of the treatife is employed upon thefe fpecific properties: a long fection upon Chemiftry is given for the purpofe of explaining them, as far as they are at prefent known, and are capable of being underftood by mere reading. The confideration of the properties of thofe rare and permanently elaftic fluids, called Air, may be faid to be a part of chemiftry; but the novelty and interefting nature of the fubject demanded a feparate fection. The concluding

cluding section relates to the general principles of electricity. Upon the whole therefore it will be seen, that the most scientific and best established parts of Natural Philosophy are first treated of, and are followed in succession by others, which are less understood.

This treatise being intended to give a clear account of the present state of Natural Philosophy, to such as possess very little mathematical knowledge, care has been taken to select such facts and experiments as tend to establish elementary truths. The varieties of experiments of the same kind are not therefore numerous; but it is hoped that the advantage of a greater number of general principles is by that means obtained. Philosophical instruments likewise are not minutely described. References to the parts of drawings are seldom read or understood: for this reason, it was thought better to explain their general construction, and leave the minutiæ to ocular inspection. The grand object, throughout, has been to relieve the memory, and assist the understanding, by conciseness and illustrative arrangement.

Those prolix disquisitions, which render the commentator less intelligible than the author commented upon, are thus avoided: neither has the affectation of familiarity, which is usually attended with a lax and unphilosophical explanation of one event by another equally obscure, been indulged. On the contrary, the author has every where endeavored to preserve that solidity of argument, and

precision of expression, which so eminently distinguish the works of the best English philosophers. And, notwithstanding the nature of the undertaking unavoidably required a deviation from those beautiful and general principles, which are obtained by strict mathematical reasoning, yet, it is presumed, that the student will find nothing in this treatise which he will be under the necessity of unlearning, when he attempts the perusal of those books to which this is offered as an introduction.

The attentive examination of other books, to which the writer of this performance has had recourse, has shewn him, that even the works of those great men, who deserve and possess the highest reputation, are not free from errors of importance. The present occasion does not require the disagreeable task of pointing them out; but this very consideration will not permit him to hope that his diligence has entirely excluded mistakes. However, he has little to fear on that account; being sensible that those who are the best able to discover them, are, at the same time, the most candid.

The liberty which has been taken in altering the words of other authors, and adapting them to the purpose of this work, would have prevented the use of formal quotations, if they had been supposed necessary; and, as the present intention is not at all historical, the names of authors have been avoided as much as was consistent with the wish of the writer to evade the suspicion of plagiarism. If plagiarism can be imputed to the author of an epitome of science, this acknowledgement must be allowed to obviate the charge.

In

In the printing, every thing which could be imagined of fervice to the book, as a manual of philofophy, has been done. A varying title at the head of each page, references from the engravings, and copious indexes, are annexed. From thefe the reader will fee, that fcarcely any fact of importance has been omitted.

The learner, who may be induced to fix his chemical reading in his memory, by recurring to experiment, which may be done with very little expence, is cautioned to beware of the danger with which it is fometimes attended. The folution, evaporation, and calcination of uninflammable matters may be performed in the common apartments of a dwelling-houfe; but the diftillation of corrofive or inflammable fubftances ought not to be attempted but in a place prepared for the purpofe. The burfting of a retort, containing any concentrated fuming acid, muft be very deftructive to furniture, as well as prejudicial to health; and ardent fpirits, refins, and the like, would endanger the houfe if a fimilar accident were to happen. It is impoffible to give advice againft the many cafualties to which chemical experiments are liable; one general maxim is, always to endeavor, from analogy, to forefee the confequence, or probable refult of the intended procefs, and when that cannot be done, to obferve the phenomena, and proceed with caution.

As almoft every fection is accompanied with a prefatory introduction, it is lefs requifite to be diffufe in this place. It remains for the Public to determine,

determine, whether the following sheets are calculated to promote the knowledge of Natural Philosophy. The author already possesses the satisfaction of having intended it.

The Reader is desired to correct the following errors of the press before he begins to peruse the Book.

VOL. I.

Page 30. line 1. *prevents*. P. 47. line ult. for AB r. AD. P. 60. l. 22. for CB r. CD. P. 79. l. 15. for 28. r. 29. P. 112. l. 20. for 35. r. 30. P. 116. *eccentricity of Mars*, 14100. P. 116. *diameter of Saturn*, 97566. P. 124. l. 12. for U read u. P. 141. l. 21. after *any* insert *other*. P. 171. l. 1. *obliquely*. P. 251. l. 23. for *bulks* r. *masses*. P. 252. l. 1. for *bulk* r. *mass*. P. 258. l. 4. *position*. P. 289. l. 17. for *less* r. *greater*. P. 304. l. 8. dele the comma after *acid*. P. 376. l. 1. for *reflection* r. *refraction*.

The following references to the plates have not been inserted in the text.

Page 33. l. 8. fig. 4. P. 38. l. 5. fig. 5. P. 38. l. 11. fig. 6. P. 41. l. 12. fig. 7. P. 41. l. ult. fig. 8. P. 59. l. 18. fig. 2. P. 61. l. 14. fig. 22.

VOL. II.

Page 15. in the note, for $x^2 = \frac{d}{a}$ read $x^2 = ad$. P. 135. l. 11. for *either* read *ether*. P. 164. l. 6. r. *effect*. P. 333. l. 19. for D r. E. P. 384. l. 18. for *if* r. *it*. P. 387. l. 24. for *flashes of* r. *flashes or*. P. 394. l. 12. for *series* r. *screw*.

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BOOK II.

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INTRO-

INTRODUCTION.

Of the Degrees or Kinds of Knowledge; and of the Rules of Philoſophizing.

THE impreſſions of external objects, acting upon the organs of ſenſe, produce ideas in the mind, and our dependance on thoſe actions being very great, we are neceſſarily determined to lay up a ſtock of general truths relating to them. This is one of the principal employments of our lives, and the maſs of truth thus acquired is called Knowledge.

Every idea has a neceſſary relation to every other idea; that is to ſay, if any aſſertion be made concerning any two ideas, that aſſertion muſt be either true or falſe. Knowledge, therefore, is a conſciouſneſs of the agreement or diſagreement of ideas with each other, when applied to a particular affirmation or propoſition reſpecting them. This conſciouſneſs is obtained either by intuition, demonſtration, or analogy.

There are ſome ideas whoſe mutual relation in certain reſpects is ſo obvious, that

nothing more is required to obtain the knowledge of it than to apply them to each other. For example; if a given body be divided into parts, and the mutual relation between the whole body and one of its parts, with refpect to magnitude, be demanded, the mind immediately conceives, with the cleareft and moft abfolute certainty, that the whole body is greater than its part. If the particular body or magnitude in contemplation be abftracted or left out, the propofition becomes general in this form, viz. every magnitude is greater than any part of the fame. This kind of knowledge is called intuitive, and the general propofitions are termed Axioms.

But the human underftanding is limited, and there are not many ideas whofe mutual relation can be thus perceived. When it is required to determine the mutual relation of two ideas, whofe agreement or difagreement cannot be intuitively perceived, the truth may frequently be obtained by the interpofition of a chain of axioms. For example *; if two right lines crofs each other, and it be demanded whether the oppofite angles are equal, invefti-

* 15. e. 1.

gation

gation becomes neceſſary. Let the oppoſite angles be called a and c, and let the contiguous angle between a and c be called b. It is intuitively perceived, that a is equal to the difference between b and two right angles; and alſo that that ſame difference is equal to c; a and c muſt conſequently be equal. Thus it is, that the relation between a and c is obtained by means of two interpoſed axioms. This method is called Demonſtration. The certainty of demonſtrative knowledge is equal to that obtained by intuition, but the conviction felt by the mind is not ſo great, eſpecially when the number of interpoſed axioms is large.

The want of axioms, and the labour of demonſtration are not the only impediments to the acquiſition of knowledge. Since knowledge is converſant with ideas only, it can be ſaid to poſſeſs reality with reſpect to external objects, ſo far only as thoſe ideas may be taken or ſubſtituted for the things they repreſent; and it is impoſſible to determine how far this may be done with propriety, even if it can be done at all. In referring from ideas to things we are liable to error, not only becauſe the compound idea of a being

confifts of an affemblage of its properties, which may be incomplete and inadequate, but likewife becaufe thofe ideas may even be quite different from any thing exifting in the being itfelf, as may be inftanced in the ideas of colour, found, pain, &c. The great perfpicuity and certainty of mathematical knowledge arifes from the fimplicity of the ideas employed, and their not depending on any external being: for, as this fcience treats only of ideas, it is of no confequence to its truths, whether geometrical figures ever had an exiftence; it being fufficient that their exiftence is poffible.

By far the greater number of our ideas being too complex and imperfect to admit of intuitive conclufions or axioms, it is evident, that in general we muft be contented with lefs proof than demonftration. Inftead therefore of endeavoring to obtain axioms, by comparing ideas, we obferve events, and from the contemplation of what has happened, we form a prefumption of what will again come to pafs. Obfervation has fhewn us, that a certain event is always followed by another determinate event; we fuppofe a relation to

fubfift

ſubſiſt between them; we imagine this relation to be neceſſary; we diſtinguiſh the prior event by the name of Cauſe, and the latter we call the Effect. This kind of knowledge, which is not founded on reaſoning, but on experience alone, may be termed Analogical, and is much leſs perfect than intuition or demonſtration. That a ſtone will deſcend to the earth, is an analogical propoſition. It cannot be demonſtrated: but, from the conſideration of a vaſt number of events of the ſame nature, a degree of probability ariſes, which commands our aſſent. It is clear, that analogical propoſitions are no more than ſtrong probabilities, from the remarkable circumſtance, that their converſe does not imply an abſurdity. To deny an intuitive or demonſtrative truth, is to aſſert an impoſſibility; but to deny an analogical truth, is only to aſſert an improbability. The underſtanding revolts at the affirmation, that a part is greater than the whole; but we ſee no impoſſibility in the aſſertion, that a ſtone, at ſome time or place, has remained in the air without a tendency to deſcend; this ſuppoſition being highly improbable, but nothing more. In fact, de-

monſtration is a collection of truths or axioms; analogy is a collection of probabilities. Simple probabilities are to analogy what axioms are to demonſtration. Now, there is no compariſon in point of certainty between axioms; all being equally true; but probabilities differ exceedingly in their degree of credibility.

Natural Philoſophy evidently admits of no other proofs than thoſe of analogy. To give ſtability to this ſcience, it is neceſſary to admit no probabilities as firſt principles of analogy, but thoſe which poſſeſs the ſtrongeſt and moſt incontrovertible reſemblance to truth. For this purpoſe, the following rules are adopted.

Rules of Philoſophizing.

I.

No more cauſes of natural things ought to be admitted than are true, and ſufficient to explain the phenomena.

II.

And therefore effects of the ſame kind are produced by the ſame cauſes.

III.

Thoſe qualities which do not vary, and are found in all bodies with which experiments can be made, ought to be admitted as qualities of all bodies in general.

BOOK

BOOK I.

SECT. I.

Of Matter in the Abstract.

CHAP. I.

Of Matter and its Properties.

MATTER is that ſubſtance of which all inanimate exiſtences are formed. It is known only to us by its properties.

The common properties of matter are EXTENSION, IMPENETRABILITY, FORM or FIGURE, INERTIA, ATTRACTION, MOTION, and REST; all which, except the two laſt, which cannot exiſt together, are found in all bodies whatſoever.

It would be, perhaps, a fruitleſs attempt, to enquire whether theſe are the only quali-

ties with which bodies are endued in common. Matter may poſſeſs many others, which our ſenſes are not adapted to obſerve, or which have hitherto eſcaped the notice of Philoſophers. But it is neceſſary to be remembered, that we are totally ignorant of the ſubſtratum in which theſe properties are united. The eſſence of matter is unknown to us. We muſt, therefore, beware of aſſuming one or more of theſe properties as compoſing that eſſence itſelf, for errors of the greateſt importance have ariſen from this ſource *.

There are other properties, called ſpecific, which are not found in all bodies; as tranſparency, opacity, fluidity, conſiſtence, and the like. But theſe ſeem to relate to the figures or motions of the parts of bodies, and are, therefore, referable to thoſe general properties. There are alſo ſeveral ſpecies of

* The doctrine of an univerſal plenum originated from a falſe definition of matter. Des Cartes placed the eſſence of matter in extenſion, from whence it naturally followed that ſpace, which is infinite, muſt be filled with it.

attraction

attraction and repulsion, which will be attended to in their proper places.

Here follow definitions of the general properties abovementioned.

EXTENSION is that affection of matter by which it occupies part of space.

IMPENETRABILITY is that by which two bodies cannot exist in the same place at the same time.

FORM, or FIGURE, consists in the relation the surfaces of a body bear to each other; and, properly speaking, is one of the modes of extension.

INERTIA, is that by which a body resists any force impelling it to change of state; *i. e.* of motion or rest.

ATTRACTION, is that by which one body continually tends to approach to, and, if not by external means prevented, does approach to, another body or bodies.

MOTION, is a continual and successive change of place. REST is the permanency or remaining of a body in the same place.

CHAP. II.

Of Extension, Impenetrability, and Form or Figure.

THOUGH the foregoing definitions may be sufficient to explain the general properties of matter when considered in the abstract, yet there are several observations worthy of notice, which will come more properly in this place than any where else.

Geometers consider extension as contained under the three dimensions of length, breadth and depth, and from thence deduce that matter is divisible ad infinitum. This being granted, the following theorems may be easily conceived.

THEOREM I.

Any quantity of matter, how small soever, and any finite space, how great soever, being given (as for example, a cube circumscribed about the orb of Saturn) it is possible for the small quantity of matter to be diffused throughout all that space, and to fill it, so that there shall

ſhall be no pore or interſtice in it whoſe diameter ſhall exceed a given line.

COROLLARY.

Hence there may be given a body, whoſe matter, if it be reduced into a ſpace abſolutely full; that ſpace may be any given part of its former magnitude.

THEOREM II.

There may be two bodies of equal bulk, whoſe quantities of matter being unequal in any proportion; yet the ſum of their pores, or the void ſpaces in each of the two bodies, ſhall be almoſt equal.

This laſt theorem is not ſo obvious as the former, but an inſtance will render it eaſy.

Suppoſe one thouſand cubic inches of gold to contain one cubic inch of matter, or in other words, when reduced into a ſpace abſolutely full, to be equal to one cubic inch: then one thouſand cubic inches of * water will contain one nineteenth part of an inch of matter when reduced. Conſequently, the void ſpaces in the gold will be nine hundred and

* Gold is nineteen times as heavy as water.

ninety

ninety-nine cubic inches, and thofe in the water nine hundred and ninety-nine cubic inches and eighteen nineteenth parts of an inch: that is, they will be nearly equal.

Yet the actual divifibility of matter can probably be carried but to a certain degree. The ultimate particles of bodies, it is moft likely, are not to be altered by any force in nature. But, neverthelefs, the above are not to be regarded as mathematical vifions, for there are many inftances which fhew to what inconceivably minute parts bodies may be actually divided.

A grain of leaf gold will cover fifty fquare inches, and contains two millions of vifible parts; but the gold which covers the filver wire, ufed in making gold lace, is fpread over a furface twelve times as great.

The animalculæ obferved in the milt of a cod-fifh are fo fmall, that many thoufands of them might ftand on the point of a needle.

Suppofing the globules of the blood in thefe animalculæ to be in the fame proportion to their bulk as the globules of a man's blood bear to his body, it appears, that the fmalleft vifible grain of fand would contain more of

of theſe globules than 10,256 of the largeſt mountains in the world would contain grains of ſand.

But this bears no compariſon with the aſtoniſhing minuteneſs of the particles of light. A candle may be eaſily ſeen in the night at two miles diſtance, even if viewed through a pin-hole in a card. It therefore follows that, at every inſtant, there is emitted light ſufficient to fill a ſphere of four miles in diameter, ſo as to leave no void ſpace of the ſize of the fiftieth part of an inch. This immenſe number of particles fly off, and are reinſtated by others, one hundred thouſand times in the ſpace of one ſecond of time. Whence it appears that they exceed the quantity of grains of ſand which might be contained in many millions of earths equal in magnitude to this we inhabit; while the conſumption of the candle is no more than the fourteenth part of a grain.

Theſe inſtances may ſerve to ſhew the amazing fineneſs of the parts of bodies, which are nevertheleſs ſtill compounded. Gold, when reduced to the thinneſt leaf, ſtill retains thoſe properties which ariſe from the modi-

fication

fication of its parts. Microſcopic animalculæ are without doubt organized bodies, and the globules of their blood are poſſeſſed of ſpecific qualities. Even the rays of light are compounded of an almoſt infinite variety of particles, which when ſeparated from each other, exhibit the powers of exciting ideas of colours. None of theſe are the ultimate particles of which all bodies are formed, for they all bear evident marks of compoſition. How inconceivably ſmall then muſt thoſe particles be!

To theſe ultimate particles alone it is, that impenetrability can be attributed. Penetration takes place in all compounded bodies. Water exiſts in the pores of wood. Air in the pores of water. Quickſilver in the pores of gold, &c. &c.

Some philoſophers have queſtioned whether impenetrability be really a property of matter; and it muſt be confeſſed, that, notwithſtanding this idea is ſo cloſely connected with our compound idea of matter, yet if we examine from whence the notion is originally obtained, we ſhall find that our knowledge is much leſs certain than we may have ſuſpected.

To make this clearer, we muſt conſider that our notion of impenetrability is derived from the ſenſe of feeling. We move the hand towards a body, and it is prevented by that body from going forward; from which we conclude, that the body poſſeſſes a part of ſpace to the excluſion of every other body, that is to ſay, that it is impenetrable.

But, in order to juſtify this concluſion, it is neceſſary that we ſhould be certain that it is the body itſelf, actually occupying ſpace, which reſiſts the preſſure; and of this we cannot be aſſured, ſince we obſerve many inſtances in which bodies afford reſiſtance to other bodies which move in ſpaces at ſome diſtance from the reſiſting body. Thus, the loadſtone in certain circumſtances reſiſts the motion of iron which approaches towards it; and there is no doubt but this reſiſtance or repulſion, if exerted on any part of a man, would afford a ſenſation ſimilar to that which ariſes from contact. If the man had not ſight, or ſome other ſenſe to perceive that the reſiſting body was really diſtant, he would, from the ſenſe of touch, conclude that

that the body was in contact with the part perceiving; and, if his force were insufficient to overcome that resistance, he would conclude the body to be impenetrable.

Now, by several experiments, which we shall have occasion to mention in the course of this work, there is the highest reason to suppose, that all bodies do exert a repulsive force on each other, and that the common effects which are attributed to contact and collision are produced by this repulsion: And, if so, why not attribute all effects of the same nature to this cause, which we know exists, instead of supposing an impenetrability that can never be proved?

If the force of repulsion be sufficiently great, it may not be in the power of any natural agent to overcome it, and, consequently all the effects of a real impenetrability will take place, though the substratum or matter itself may not be impenetrable, or even extended.

It is not in our power to determine, whether extension or impenetrability be essentially necessary to existence; but certain it is, that we

we have ideas of exiſtences in which neither the one nor the other are found: no one thinks the images in the foci of optical inſtruments impenetrable, which are nevertheleſs taken for real beings, eſpecially that in the air before a concave mirror; and in the idea we have of our thinking part, we are ſo far from including extenſion, that it appears abſurd to imagine it diviſible, though diviſibility is a neceſſary property or mode of extenſion.

From theſe conſiderations, it is evident, that we are not ſo certain of the impenetrability, or even the extenſion of matter, as we are of its inertia, attraction, and mobility.

But, though certainty be not attainable in this caſe, yet we may attempt to diſcover the greater probability; that is, whether it be more probable, that the particles of matter are beings poſſeſſed of a finite power of repulſion which prevents their mutual approach, but does not render mutual penetration or coincidence in the ſame part of ſpace impoſſible, on the application of force ſufficient to overcome that repulſion; or whether they be impenetrable atoms, which,

consequently must resist such coincidence with an infinite force?

Here we must attend to the facts. If the repulsion continually increased as the distance of the bodies decreased, we might conclude, that it was the only cause of the apparent impenetrability of bodies; but, as in the loadstone, there is a certain small distance at which repulsion ceases, and attraction takes place, so in compressing bodies together, with a certain degree of pressure the distance is at length diminished sufficiently for the bodies to adhere. The phenomena are probably similar; but, at all events, the cohesion of the parts of bodies shews a mutual attraction; and it is not easy to explain why the parts should not mutually penetrate and coincide, when the repulsion on which their impenetrability was supposed to depend, has ceased and given place to attraction. And on this account, the doctrine of impenetrable atoms seems the most probable.

The quantity of matter in the universe is much less than is generally imagined. This may be deduced from what has been said already on this subject; but more especially from

from the properties of tranſparent bodies. Light paſſes through theſe in all directions without the leaſt difficulty. The focus of a burning mirror, which augments the denſity of the ſun's rays upwards of three thouſand times, may be received in the bodies of glaſs or water, without producing any effect; ſo far are the particles of thoſe ſubſtances from impeding the paſſage of light. And the bottom of the ſea has been diſcovered at a greater depth than ſixty feet. It is not improbable that the real matter in a ſmall piece of glaſs may bear a leſs proportion to its bulk than that bulk does to the whole earth. Whence the electric matter paſſes with an unmeaſurable velocity through the pores of gold and other bodies, and the magnetic power exerts itſelf undiminiſhed through all ſubſtances (iron excepted).

To render the poſſibility of this more evident, let a body be ſuppoſed to be ſo conſtructed, as to have as much vacuity as matter; then half the body would be vacuous. Suppoſe the particles of which it is compoſed to be conſtructed in the ſame manner; then the vacuity becomes three-

fourths of the ſpace extended. Again, let theſe laſt mentioned particles be conſtructed in the ſame manner; the vacuity will then be ſeven-eighths. And the ſeries being carried forward to the tenth order of particles, the vacuity will exceed the matter one thouſand and twenty-three times.

To the form or figure of bodies are to be attributed numberleſs effects we obſerve daily. And to this property is owing moſt of thoſe qualities which are called ſpecific. Fluidity, conſiſtency, elaſticity, and the like, are probably the conſequences of certain configurations of the particles of thoſe bodies in which they are found, or at leaſt of the admiſſion of certain parts differently formed into the texture of the fluid, conſiſtent or elaſtic, &c. body. But more of this hereafter.

CHAP. III.

Of the Inertia and Motion or Reſt.

IT is chiefly from the inertia that we obtain a knowledge of the relative quantities of matter in bodies. The quantities of matter in bodies

bodies abſolutely ſimilar in compoſition, are determined by their extenſion; but in diſſimilar bodies the ratio does not hold. Now, in bodies ſimilar in compoſition, we obſerve that the inertia follows the proportion of the extenſion, that is, the proportion of the maſs of matter; and from thence, by applying the proportion of the inertia to diſſimilar bodies, we obtain a knowledge of their maſſes. Thus, for example, the quantity of matter in one cubic inch of gold is as 1, in two cubic inches as 2, in three cubic inches as 3, and ſo forth: this we gather from the extenſion, and alſo from the inertia, both which, in this caſe, follow the ſame proportion. But if a cubic inch of copper be added, though the extenſion be augmented as 1, yet the inertia increaſes only as $\frac{1}{2}$; therefore, either the extenſion or the inertia is not the proper meaſure of the maſs; and, as we can more readily conceive that the extenſion, or ſpace occupied within the external limits of the body, may by poroſity in the body, ceaſe to be the meaſure, than that the inertia of the ultimate parts of matter ſhould vary; we conclude, that the

quantity of matter is as the quantity of the inertia; though it muſt be allowed that neither poſition is phyſically demonſtrable.

The inertia of matter being that by which it reſiſts any change of ſtate with regard to motion or reſt, is meaſured by the force which is required to produce a given change; that is to ſay, the force required to give a certain degree of velocity to a body at reſt A, containing ten parts of matter, is five times as great as would produce the ſame effect on a body at reſt B, containing two parts.

This force in a moving body is called the quantity of motion, and is meaſured by the maſs of matter multiplied by the velocity; for the whole motion of a body is the ſum of the motions of all its parts. Therefore in the laſt mentioned inſtance, the body A moves with five times the force that B moves with, though the velocity is the ſame in both. But if the velocity of B were to be augmented five times, the quantities of motion would then be equal; that of A being expreſſed by 10, multiplied by 1, and that of B being 2, multiplied by 5.

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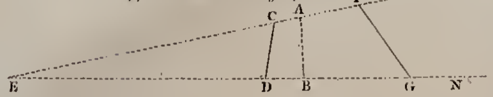
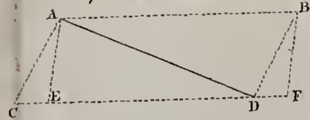
No. I.

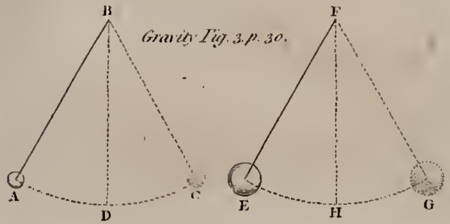
Apparent Motion Fig.1.p.24.



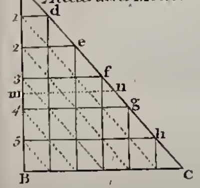
Compounded Motion Fig.2.p.27.



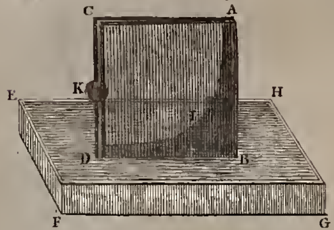
Gravity Fig.3.p.30.



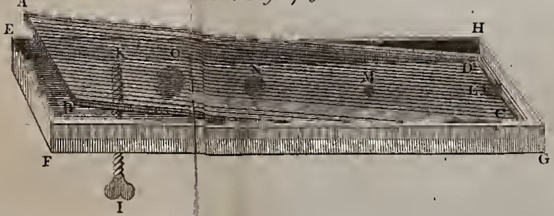
Accelerated Motion Fig 4.p.33.



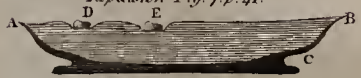
Attraction of Cohesion Fig.5.p.38.



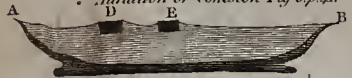
Attraction of Cohesion Fig.6.p.38.



Repulsion Fig.7.p.41.



Attraction of Cohesion Fig 8.p.41.



Motion and reſt are diſtinguiſhed into abſolute and relative. Abſolute motion is the removal of a body from one part of ſpace to another. Relative motion is a ſucceſſive change of ſituation with reſpect to another body, though that body may not be at reſt. Thus, a man ſitting, in a barge in motion, is relatively at reſt, that is, with reſpect to the parts of the barge: but abſolutely in motion; being removed, with the veſſel, from one part of ſpace to another. On the contrary, the bargeman, who fixes a ſtaff in the ground, and gives motion to the barge by walking along its gunwale, is abſolutely at reſt, for the ſtaff againſt which he leans is fixed; but relatively in motion, ſince, with reſpect to the veſſel, he walks from one end to the other. But if the earth be ſuppoſed in motion, the abſolute motions of the barge and its contents will be compounded of the ſums or differences of their relative motions reſpectively, when applied to the abſolute motion of the earth.

There is another diſtinction in motion, by which it is called apparent or angular motion, and which depends on an optical fallacy.

 Thus

Thus to an eye at E, (fig. 1.) a body which moves from C to D, from F to G, or through any right lined ſpace between the lines EM and EN will apparently deſcribe the line AB, though the real motions are very different. And if a body move, either directly towards or directly from the eye, it will be apparently at reſt. It is true, that, from other circumſtances, we have acquired the habit of diſtinguiſhing different motions which are made obliquely to the eye; but where thoſe circumſtances are wanting, as in the heavens, it requires no ſmall degree of attention to diſtinguiſh the real from the apparent motion.

The three following laws are ſufficient to anſwer all the phenomena of motion.

LAW I.

Every body continues in its ſtate of reſt, or of uniform motion in a right line, unleſs compelled to change that ſtate by forces impreſſed.

Matter at reſt, being endued with no power of moving itſelf, would remain ſo for ever, unleſs impelled by ſome external cauſe.

We have alſo daily proofs, that a body in motion will continue to move uniformly in a right

a right line, unleſs prevented by ſome other agent. The reſiſtance of the air, and the force of gravity in a ſhort time deſtroy the motion of all projectiles, which otherwiſe by the vis inertiæ would continue for ever.

LAW II.

All * change of motion is in proportion to the force impreſſed, and is made in the line of direction in which that force is impreſſed.

If any force produces motion, a double force will produce a double quantity, and a triple force a triple quantity, whether it be impreſſed all at once, or by ſucceſſive degrees. And this motion (ſince it always coincides with the direction of the generating force) if the body be already in motion, either increaſes the ſame by conſpiring therewith, or diminiſhes it by a contrary occurſe, or is added to it obliquely, being compounded with it according to the direction of the two motions.

LAW III.

Action and reaction are always equal and contrary; or, the mutual actions of two

* *Change of motion* muſt be underſtood to ſignify, as well the *change from reſt to motion*, as the change produced in a body already in motion.

bodies

bodies are always equal, and in contrary directions.

If a ſtone be preſſed by the finger, the finger is equally preſſed by the ſtone. If a horſe draws a ſtone, the ſtone draws the horſe equally backwards, for the rope is equally ſtretched towards both. If one body impels another, it will itſelf ſuffer an equal change of motion by the reaction in a contrary direction. By this means the changes of motion, tho' not of velocity, are always equal.

To illuſtrate this a little more. Suppoſe a horſe proceeds with a quantity of motion expreſſed by the number 3, and that it would require a force equal to 2 to move a certain ſtone. The horſe then drawing, proceeds with a force equal to 1, the reaction of the ſtone deſtroying as much force as the action communicates to it.

From theſe laws the following corollaries are eaſily deduced, which may be applied to ſolve all the effects which can be produced by the mechanical powers.

COROLLARY

COROLLARY I.

A body impelled by two forces acting in the direction of the two fides of a parallelogram will defcribe the diagonal in the fame time, as, under the impulfe of one of the forces, it would have defcribed one of the fides.

A body at A (fig. 2.) would be carried with an uniform motion in a given time to B, by the fingle force M impreffed at A; and by the fingle force N, impreffed at the fame place, would be carried from A to C; Complete the parallelogram ABDC, and by the combined forces, it will be carried in the fame time in the diagonal from A to D. For fince the force N acts according to the direction of the line AC, which is parallel to BD; it will by Law II. in no refpect alter the velocity of approaching to BD, which was produced by the other force. Therefore, the body will in the fame time arrive at the line BD, whether the force N be impreffed or not; and at the end of the time will be found fomewhere in the faid line BD. By the fame manner of arguing, it will at the end of the time be found fomewhere in the line CD, which muft

of

of consequence be in that place where they intersect each other. Its motion will be in a right line by Law I.

COROLLARY II.

Hence also appears the composition of a direct force AD from any two oblique forces AB and BD, and on the contrary, the resolution of a direct force into any two oblique forces, AB and BD, which composition and resolution is abundantly confirmed by mechanics.

COROLLARY III.

The quantity of motion which is obtained by taking the sum of the motions made in the same direction, or the difference of those made in contrary directions, is not changed by the mutual action of the bodies.

For action and reaction being equal, by Law III. will therefore occasion equal changes in the motions, but in contrary directions. Consequently, if the motions are both made in the same direction, whatever is added to the motion of the impelled body must be subtracted from that of the impelling body, and the sum will remain the same. But if the bodies meet directly; the quantity of motion destroyed being

being equal in each, the difference of the motions made in contrary directions will remain unchanged.

CHAP. IV.

Of Attraction.

WHEN by reducing compound effects to ſimple ones, we have arrived at the moſt ſimple of all natural cauſes, we are obliged to terminate our ſearch by immediate reference to the neceſſary ſelf-exiſtent firſt cauſe. Phenomena are wanting to determine whether attraction depends on the immediate fiat of the Deity, or on other intervening cauſes. The latter is moſt probable, but the reaſons on which that probability is founded, cannot be diſcuſſed in this place. At preſent we are only to conſider it as the unknown cauſe of effects, whoſe exiſtence cannot be doubted, and from thoſe effects to determine its mode of action.

Attraction, as far as it comes under our obſervation, may be divided into three claſſes, viz. gravitation, coheſion, and ſpecific.

Gravitation is that force by which bodies fall to each other. The vicinity of the earth,

which attracts every thing to itſelf, prevetns its effects between ſmaller bodies from appearing; but the attraction of the mountain of Schehallien in Scotland, upon the ball of a pendulum was found by a very accurate ſet of obſervations to be conſiderable.

This power is found to act on all bodies preciſely according to the quantity of matter in each, which is diſcovered by the vibration of pendulums, thus. Let the two unequal bodies A and E (fig. 3.) be ſuſpended by threads of exactly the ſame length, and be let fall at the ſame time from the points A and E, (in the arches AC and EG) which are at equal diſtances from the two loweſt points D and H. Then the vibrations of each will be performed in equal times, and conſequently the velocities will be equal. Whence the quantity of motion in each (being the product of its maſs of matter multiplied by its velocity) will be in proportion to the maſs of matter in each. But, by Law II. the force producing motion is in proportion to the quantity of motion produced. Therefore, the force of attraction is in proportion to the quantities of matter in bodies.

This likewiſe appears in falling bodies, all which being let go from equal heights (how different ſoever in weight) arrive at the ground in the ſame time,* that is, with quantities of motion in proportion to their reſpective quantities of matter.

Gravitation acts on all bodies at all times, and that equally whether in motion or at reſt, as is evident from the velocities of falling bodies, which are uniformly accelerated during the whole of their courſe. That a force conſtantly and equally acting, will produce an uniform acceleration of velocity is plain, from the following conſiderations. Suppoſe a body A begins to move (by the impulſe of gravity impreſſed at that inſtant) with a velocity expreſſed by the number 1, the next inſtant another impulſe will generate a velocity equal to the former. It will therefore move with the velocity 2, and at the third inſtant with the velocity 3, &c. for the pre-

* The reſiſtance of the air is not here conſidered, for the ſake of perſpicuity, though it very ſenſibly impedes all motions performed in it. A guinea will arrive at the ground in leſs time than a feather; but in the receiver of an air-pump (out of which the air is exhauſted) they both fall in the ſame time.

ceding

ceding velocities are not in any reſpect diminiſhed or altered by the ſucceeding impulſes. If then the impulſes are equal and equidiſtant in time, the generated motion will be uniformly accelerated; and the velocity (which in this caſe may be conſidered as the motion, for the maſs of matter does not alter) will be in proportion to the time; that is, if the velocity in 5 inſtants be expreſſed by 5, that produced in 10 inſtants will be 10, &c. This holds good, let the number of impulſes in a given time be ever ſo great. But the number muſt here be conſidered as infinite, for gravity ceaſes not to act for the leaſt portion of time, and therefore the acceleration continues uniformly through every part of the motion.

The ſpace deſcribed by an uniformly accelerated motion in a given time, may be conceived to be the ſum of an infinite number of ſpaces produced by a like number of uniformly increaſing velocities. Theſe ſpaces will be as the velocities. Therefore, as the ſum of the velocities in any given time is to the ſum of the velocities in any other given time, ſo is the (ſum of the ſpaces or) ſpace

deſcribed

deſcribed in the firſt given time to the (ſum of the ſpaces or) ſpace deſcribed in the other given time. But the ſums of the velocities, for any terms of time taken from the beginning of the motion, are to each other as the ſquares of the time; as appears from the following.

In the triangle ABC, let the equal diviſions A 1, 2, 3, &c. on the ſide AB repreſent equal parts of the time of an uniformly accelerated motion. Then the parallel lines 1 d, 2 e, 3 f, &c. may repreſent the velocities at the ſeveral inſtants, 1, 2, 3, &c. for they are in proportion to the times A 1, A 2, A 3, &c. And in like manner for any other part of the time as A m, the velocity generated will be repreſented by its correſpondent ordinate mn. And the ſum of the ordinates correſponding with any part of the time will repreſent the ſum of the velocities. But the ſum of the ordinates is the area contained between the ordinates of the firſt and laſt inſtants of the time. And theſe areas, when taken from the beginning A, are as the ſquares of the times A 1, A 2, A 3, &c. (by the property of ſimilar figures). Therefore the

ſums of the velocities, and conſequently the ſpaces deſcribed in any given terms of time taken from the beginning of an uniformly accelerated motion, are to each other as the ſquares of the times. Hence it likewiſe appears, that the ſpaces deſcribed in equal ſucceſſive parts of time, are as (the areas contained between A and 1 d, 1 d and 2 e, 2 e and 3 f, &c. which areas are to each other as) the odd numbers 1, 3, 5, 7; 9, &c. as appears by inſpection from the number of equal and ſimilar ſmall triangles contained in each.

The force of gravity decreaſes in the reciprocal proportion of the ſquares of the diſtance of the gravitating bodies. This diminution is too inconſiderable to be perceived at ſmall diſtances from the earth, but is very ſenſible in the effect it has on the motions of the planets.

CHAP. V.

Of the Attraction of Cohesion, and of specific Attractions.

THE attraction of cohesion is that force by which bodies or their particles adhere to each other.

The attraction which one body or mass of matter exerts upon another, is the sum of the attractions of all its particles. Now, if an attractive force acted equally at any assumed distance, masses of matter would mutually attract each other according to the same laws as the particles of which they are composed do act. But that not being the case, it is of the utmost consequence to attend to the different effects of the attractions of the minute particles themselves, and of the aggregates composed of such particles.

It is demonstrated, that if the forces by which the particles of bodies tend towards each other do decrease in the proportion of the squares of their distances, the attractive

force of two ſimilar bodies compoſed of ſuch particles, will be governed by the ſame law; relation being had to the diſtances of their centers: and conſequently, it will not be ſenſibly greater when they are in contact, than when they are at a ſmall diſtance from each other. But if the firſt mentioned forces do decreaſe in the proportion of the cubes of their diſtances, or in any greater proportion, the latter will decreaſe after a much higher rate, and the bodies, when in contact, will attract each other very much more forcibly than when ſeparated at the leaſt diſtance from each other.

The firſt of theſe attractions is gravity, and the latter appears to be the attraction of coheſion, for its force is vaſtly leſs at the leaſt diſtance, than at the place of contact.

In conſequence of this law, ſeveral deductions are made, which are found to agree with the phenomena of this kind of attraction, as,

Thoſe particles which are poſſeſſed of large ſurfaces of contact, adhere more ſtrongly together, and form bodies which are called hard.

Thofe particles which touch each other in few points, compofe bodies which are foft or fluid, on account of the fmall force with which their parts adhere together.

And hence probably may be explained the elafticity of fome bodies; for it feems to depend on the cohefive force which reftores the particles to their firft (relative) fituation, when by any external impulfe, they have been removed to a very fmall diftance from each other.

Many things remain for the induftry of future philofophers concerning this very powerful agent in nature.

By this power the drops of all fluids affume a round form, and polifhed plates of metal adhere together with a prodigious force, which is exemplified by paring a fmall part from each of two leaden bullets, and preffing the furfaces together; in which cafe, with a furface of contact not exceeding the twentieth part of a fquare inch, it will frequently require the force of 100 lb. to feparate them.

By this power alfo it is, that liquids rife into the fubftance of bread, fponge, and other

porous bodies; and are sustained in open * capillary tubes a considerable height above the level. This height is in the reciprocal proportion of the diameters of the tubes.

Two plain glass plates touching each other at the line AB, and separated at CD, by a small obstacle K, being placed in the vessel of water EFGH. The water rises between them in the figure DIA, which is that of an hyperbola.

Let two plain glass plates ABCD, be lightly moistened with oil of oranges, and placed one upon the other, so as to touch at the line AB, being kept separate at CD, by the small obstacle L interposed. In this situation let them be placed in the horizontal box, EFGH, the part CD resting on its bottom, and the other part towards AB, resting on the upper end of the perpendicular screw IK, which is fixed in the box for the purpose of raising the plates to any desired angle

* *Capillary* tubes are so termed from the smallness of their bore, being *capillaris*, or like a hair; but this effect is sensible even in tubes of one-fourth of an inch diameter.

of

of elevation. Then a drop of the above mentioned oil being applied in the opening CD, will be attracted by the two plates, and will proceed with an accelerated motion towards AB, if the plates are kept in an horizontal position. But if the end AB be raised by means of the screw, to a considerable angle, the drop will remain suspended in its course somewhere between CD and AB, suppose at N, and if the elevation be encreased, it will return towards CD, its weight overpowering the attraction of the plates.

Now, since the weight of the drop continues unaltered, it will not be difficult to find its tendency to return, or that part of its weight which is exerted in the inclined descent. For the proportion between that part and the whole, is as the height of the plane to its length, as will hereafter be shewn. And since the two powers, namely, the attraction by which the drop tends upwards, and that part of its weight which is exerted in the contrary direction, are equal when it remains suspended, the measure or quantity of the one will express the measure or quantity of the other. By these means it is easy

to determine the attractive force; which appears to increase in the reciprocal proportion of the squares of the distances of the middle of the drop, from the end where the plates are in contact. That is, simply in a reciprocal proportion, because the drop enlarges its surface as the space becomes narrower; and again, simply in a reciprocal proportion, because the attraction increases, the nearer the plates approach each other.

This cohesive attraction extends to an extremely small distance from bodies, and where its power terminates, repulsion takes place, of which we shall subjoin a few instances.

All hard bodies require a considerable force to bring them into contact, as appears by compressing a convex lens and plane glass together, which exhibit different appearances at the very point of (supposed) contact, according to the different degrees of compression; as also from the passage of the electric matter through metallic chains. Of which more hereafter.

When it rains on the surface of a vessel of water, small drops may frequently be seen running in all directions, which do not mix

 with

with the reſt of the water for ſeveral ſeconds.

Hence likewiſe it is that bodies ſpecifically heavier than water may be made to ſwim on its ſurface; for, if by their repulſion a quantity of water is diſplaced equal in weight to the ſolid, it will not ſink.

Dry needles or thin plates of metal ſwim on water, and form cavities of a curve lined form, extending to a conſiderable diſtance from the body.

Let ACB repreſent the ſection of a veſſel of water, on whoſe ſurface AB is laid two circular plates of tinfoil, on each of which is placed a ſmall curtain ring, or ſome ſuch body, to encreaſe its weight, and cauſe it to ſink further beneath the ſurface. By this means they will form two cavities about one-tenth of an inch deep, and extending half an inch from the circumferences of the plates. If they are brought within the diſtance of an inch from each other, they will ruſh together with an accelerated motion.

Things remaining as in the laſt experiment, let D and E be two pieces of wet cork of the

the ſame dimenſions. The water then by adhering to their ſides, will form a curve lined protuberance extending about half an inch from their circumferences, and being brought within an inch of each other, they will ruſh together as before.

To account for theſe appearances, it is to be remembered, that action and reaction are equal. The plate of tinfoil by its repulſion acts on the water and prevents its filling the cavity, and the water by its weight reacts on the plate; but as this reaction is the ſame on all ſides, no motion is produced. But when the two plates approach each other near enough to unite their reſpective cavities, the weight of the water between them being decreaſed, its reaction is leſs than that which prevails on the oppoſite parts of the circumferences: conſequently they move in the direction of the greater preſſure, that is towards each other.

In the latter caſe, the reaction is in a contrary direction, being oppoſed to an attractive, inſtead of a repulſive force, and the circumſtance by which motion is produced being likewiſe contrary, the effect is the ſame in both

both cafes. A depreffion of the furface between the two corks will occafion them to recede from each other; but in the prefent inftance, the quantity of water being increafed by elevation, caufes them to approach by its reaction, which is greater than that exerted on the external parts of the peripheries.

Specific attraction is ufed to fignify fuch attractions as are found only in particular bodies, or in bodies in particular circumftances: thus the loadftone attracts iron; iron attracts iron, provided it be firft applied to the loadftone; electrified bodies attract bodies which are in certain circumftances, and repel them when thofe circumftances are changed. It is by a diligent obfervation of thefe kinds of attraction and repulfion, that we may hope to difcover the caufes of gravity, and the other principal agents in the mundane fyftem.

In the mean time, it muft not be imagined that the doctrine of *occult caufes* is revived, becaufe philofophers folve the appearances of nature by attraction and repulfion, while they confefs themfelves ignorant of their

caufe.

cause. It is enough that such powers do really exist. That John is the son of Thomas is not less true, because we are unacquainted with the father of Thomas. And in like manner, it is not less true, that gravity is the cause of the descent of heavy bodies, though the cause of gravity is unknown to us. We must not reject all knowledge, because we cannot arrive at perfection itself.

BOOK I.

SECT. II.

Of Bodies in Motion.

HAVING thus given as concife an account of the general affections of matter as the nature of the fubject would admit of, we fhall proceed to fhew the effects of motion deduced from the above principles and powers.

CHAP. I.

Of the Mechanical Powers.

WHEN we contemplate the fcale of animated beings, at the head of which we are placed, it evidently appears that the dominion we poffefs over the whole cannot be attributed to fuperiority of ftrength or bodily power. Many animals exceed

exceed us in every respect of that sort, but the wisdom of the Almighty has bestowed on us a more than ample compensation. That intelligence which, faintly imitating its great Author, commands the powers of nature, is capable of infinitely greater things than the mere efforts of brute strength. It is owing to the presence of man that the most fertile country does not put on the chearless aspect of the desart. Where the sciences flourish, the whole face of nature is enlivened; in proportion as they are neglected, nations become savage, and the appearance of things is changed for the worse. Experience and reason both join in proof of this. Nay, it scarce seems to be an exaggeration to affirm, that the most enlightened of mankind exceed the savage part of their species more than these latter do the upper classes of irrational animals. This distinguishing preeminence shews itself in nothing more conspicuously than in the exercise of the mechanical powers, as they are commonly called.

The mechanical powers are usually reckoned to be six, viz. the lever, the axis and

and wheel, the pully or tackle, the inclined plane, the wedge, and the ſcrew.

Theſe inſtruments are conſidered as having different weights applied to their parts, and the effects are demonſtrated from the laws of motion. And ſince every force may be meaſured by the weight it can ſuſtain, that which is proved of weights will be equally true of forces.

It may not be amiſs in this place to illuſtrate the ſecond Corollary to the third Law of motion, concerning compoſition and reſolution, by calling to mind that,

If in any compounded motion or force, the quantity and direction of one of the compounding forces be given, the quantity and direction of the other may eaſily be found: e. g.

In the compounded motion or force * AD, (fig. 1.) it is known that one of the compounding forces was impreſſed at A in the direction and quantity of the line AB. Join BD, and draw AC from A, parallel and equal to

* Here and elſewhere the effect is uſed for the cauſe, for the ſake of conciſe expreſſion. Properly ſpeaking, it ſhould be *in the compounded motion, which, in a given time, would uniformly deſcribe the line or ſpace* AB, &c.

BD.

BD. AC will repreſent the direction and quantity of the other compounding force.

For it is proved by the firſt Corollary, that with theſe forces the motion AD will be produced.

And, if in any compounded motion or force, the directions of the compounding forces be given, their quantities may be eaſily found: e. g.

In the compounded motion or force, AD, (fig. 1.) it is known, that one of the compounding forces was impreſſed at A, in the direction AB, and the other likewiſe at A, in the direction AC. Parallel to AC, from D, draw the line DB, interſecting AB in the point B. From A upon the line AC, ſet off the ſpace AC equal to DB. AC and AB will repreſent the quantities of the forces.

For it is proved by the firſt Corollary, that with theſe forces the motion AD will be produced.

Laſtly, if in any compounded motion or force, whoſe direction is known, the direction and quantity of one of the compounding forces be given, together with the direction of the other, the quantities of the com-

pounded

pounded motion or force, and of the laſt mentioned compounding force may be eaſily found; e. g.

The compounded motion or force which is produced in the direction AD, received, at its beginning or generation, an impreſſed force in the direction and quantity AB, at the ſame inſtant in which another force was impreſſed in the direction AC. From B parallel to AC, draw the line BD interſecting AD in the point D. Upon AC, ſet off the ſpace AC equal to BD. AC will repreſent the quantity of the compounding force impreſſed in the direction AC, and AD will repreſent the quantity of the compounded motion or force in the direction AD.

For it is proved by the firſt Corollary, that with theſe forces the motion or force AD will be produced.

And that no other quantity or direction of force will in theſe circumſtances produce the motion AD, may be proved thus.

In the compounded motion or force AD, the quantity and direction AB of one of the compounding forces being given, it is found that the other compounding force is in the

quantity and direction AC, (fig. 1.) Now, I ſay, that no other quantity or direction of force, in conjunction with AB, will produce the motion or force AD. For, if ſo, let AE repreſent the force which does not coincide with AC, parallel to which draw BF, then will the diſtance DF be equal to CE. With the forces AB, AE, the moving body will, at the end of its motion be found at F by Corol. 1. But the ſuppoſition requires, that it ſhould be found in D, and is therefore falſe.

In the ſame manner it is proved of any other aſſumed force; and by this method of arguing the concluſions in the other inſtances juſt mentioned, are found to be determinate and preciſe.

And ſince AC is always parallel and equal to BD; BD may in all caſes repreſent the quantity and direction of the force AC.

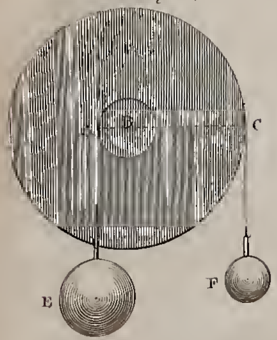
Theſe things being attended to, it will not be difficult to explain the effects of the mechanical powers in every poſſible ſituation.

CHAP.

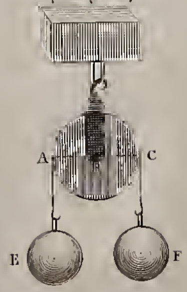
face p.55. Vol. I.

No. III.

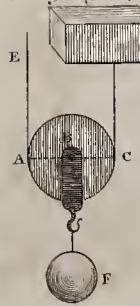
Axis & Wheel Fig.15.p.56.



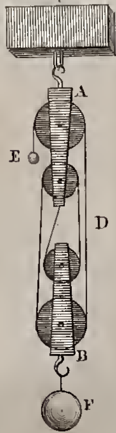
Pulley Fig.16.p.57.



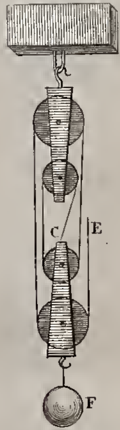
Pulley. Fig.17.p.57.



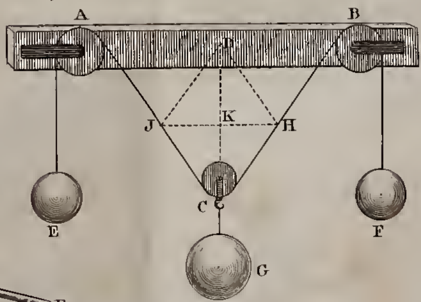
Tackle Fig.18.p.58.



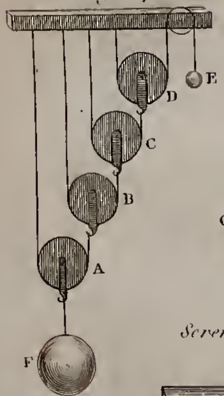
Tackle Fig.19.p.58.

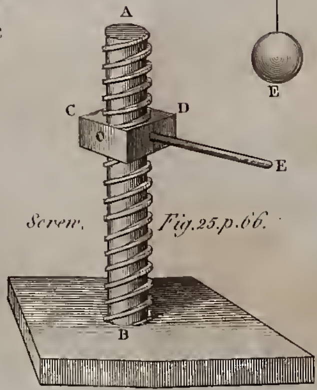


Composition & Resolution of Forces, Fig.21.p.59.



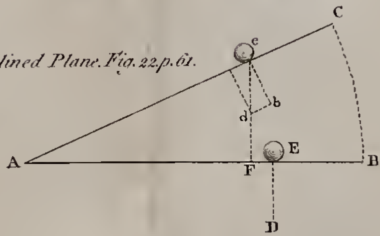
Tackle, Fig.20.p.59.



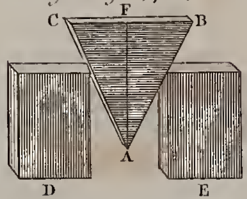


Screw. Fig.25.p.66.

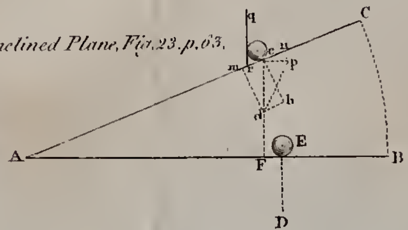
Inclined Plane. Fig.22.p.61.



Wedge. Fig.24.p.64.



Inclined Plane. Fig.23.p.63.



CHAP. II.

Of the Lever.

THE LEVER is a moveable line impreſſed upon by three forces, the middle one of which is contrary in direction to the other two.

One of theſe forces is produced by the reaction of a fixed body, and is called the fulcrum.

Let AC, (fig. 9.) repreſent an horizontal lever. At the point B, equidiſtant from A and C, is placed the fulcrum D, and at the extremities A and C are hung the equal weights E and F. Then the lever will be at reſt, the weights E and F being in equilibrio. For the forces with which they tend to produce motion are equal, and are applied in directions exactly contrary, viz. in tangents to the circle in which the extremities would move.

It is likewiſe evident, that if the radii AB and BC are not in a right line, the equal forces will nevertheleſs be in equilibrio, if they are applied in the directions of the tangents: thus, if BC be bent to the poſition Bc, and the force F be there applied in the direction cf, the equilibrium will remain as before.

If two contrary forces be applied to a lever at unequal diſtances from the fulcrum, they will equiponderate when the forces are to each other in the reciprocal proportion of their diſtances.

Let AC, (fig. 10.) repreſent a lever, whoſe radius AB is three times as long as BC. At A is ſuſpended the weight E of one pound, and at C is ſuſpended the weight F of three pounds. Then, I ſay, theſe weights will equiponderate. With the radius BA deſcribe the arc Ac, interſecting CF at c. Join Bc and the force F may be conceived to act at c on the arm Bc. Let AG repreſent the force of E, and cF, being three times as long, will repreſent the force of F. This force cF may

be resolved into two others, cJ in the direction of Bc, and cH in the direction of the tangent, and their quantities are determined by drawing the lines FH and FJ. Now cJ has no effect in moving the arm Bc. It is the force cH alone that tends to produce motion towards H. The triangles BCc and cHF are similar, therefore Bc : BC : : cF : cH. But Bc : BC, as 3 to 1, whence the force cH is $\frac{1}{3}$ of cF, as is likewise AG by the condition. Consequently Hc and AG are equal, and will be in equilibrio. Which was to be proved. And the conclusion will be the same, when the weights are to each other in any other ratio, provided the arms of the lever AB and BC are reciprocally in the same proportion.

By the resolution of force, it appears, that if two contrary forces be applied to a strait lever at distances from the fulcrum in the reciprocal proportion of their quantities, and in directions always parallel to each other; the lever will remain at rest in any position.

For, let the forces AE, CF (fig. 11.) be resolved: AE into AG and GE; and CF into

CH and HF; and the forces, which tend to produce motion, will in all poſitions be to each other in the ratio of the forces applied; i. e. AE : CF : : AG : CH, the triangles AGE and CHF being ſimilar.

Many curious and uſeful effects may be produced by levers, whoſe arms are bent into an angle; but the limits of this work does not permit us to enlarge upon them.

It is evident, that all which has been ſaid concerning the lever is equally true, when the contrary forces are applied on the ſame ſide of the fulcrum.

On the lever AB (fig. 12.) if the weight E of one pound be applied at A, and the weight F of three pounds at C, ſo that their diſtances AB and CB, from the fulcrum B, may be as three to one, they will equiponderate. Which is proved by applying the reaſoning at fig. 10. to the preſent figure.

Since, of the three forces which act on a lever, the two which are applied at the extremes are always in a contrary direction to that which is applied in the ſpace between them; this laſt force will ſuſtain the effects of the other two. Or in other words, if the

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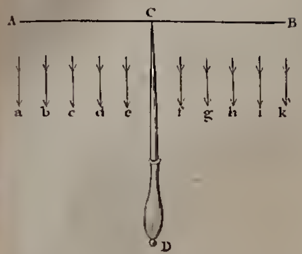
No. II.

Center of Gravity, Fig 26. p. 72.



Center of Gravity, Fig. 27. p. 73.

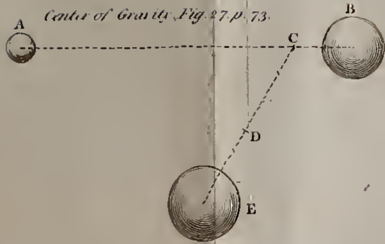
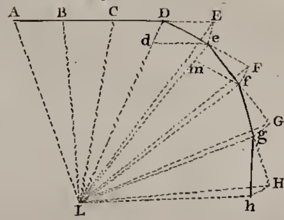
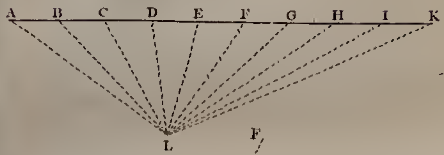


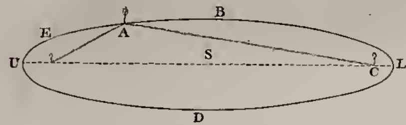
Fig 29. p. 79.



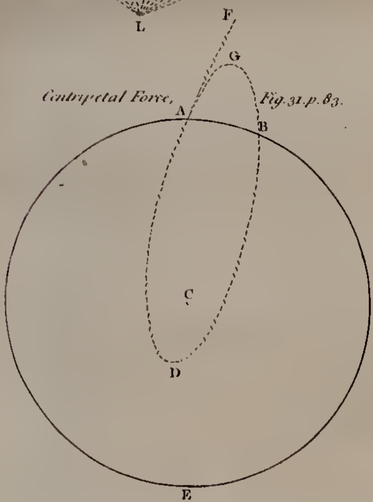
Centripetal Force, Fig. 28. p. 79



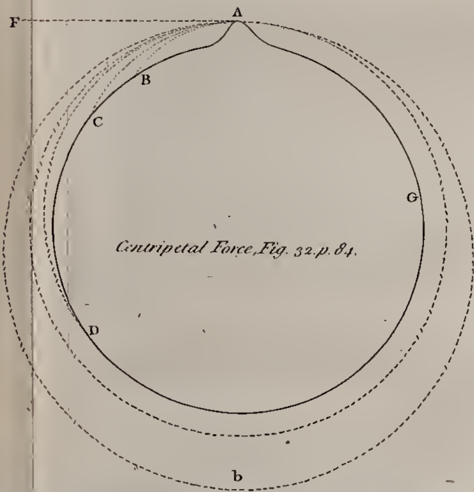
Ellipsis, Fig. 30. p. 83.



Centripetal Force, Fig. 31. p. 83.



Centripetal Force, Fig. 32. p. 84.



fulcrum be placed between the weights, it will be acted upon by, or will ſuſtain their ſum; but if the weights are on the ſame ſide of the fulcrum, it will be acted upon by their difference.

On the principle of the lever are made, ſcales for weighing different quantities of various kinds of ſubſtances; the ſteelyard, which anſwers the ſame purpoſe by a ſingle weight, which is removed to different diſtances from the fulcrum on a graduated arm, according as the body to be weighed is more or leſs in quantity; and the bent lever balance, which by the revolution of a fixed weight increaſing in power as it aſcends in the arc of a circle indicates the weight of the counterpoiſe. ABC (fig. 13.) is a bent lever, ſupported on its axis or fulcrum B in the pillar JH. At A is ſuſpended the ſcale E, and at C is affixed a weight: draw the horizontal line KG, through the fulcrum, on which from A and C, let fall the perpendiculars AK and CD. Then if BK and BD are reciprocally in proportion to the weights at A and C, they will be in equilibrio, but if not, the weight C will move along the arc

FG, till that ratio is obtained. It is eaſy to graduate the plate FG ſo as to expreſs the weight in E by the poſition of C.

On this principle alſo depends the motions of animals, the overturning or lifting great weights by means of iron levers called *crows*, the action of nutcrackers, pincers, and many other inſtruments of the ſame nature.

C H A P. III.

Of the Axis and Wheel, and of the Pulley or Tackle.

THE AXIS AND WHEEL may be conſidered as a lever, one of the forces being applied at the circumference of the axis, and the other at the circumference of the wheel, the central line of the axis being as it were the fulcrum. Fig. 14. is a perſpective view of the inſtrument, and fig. 15. is a ſection of the ſame at right angles to the axis. Then, if AB, the ſemidiameter of the axis, be to BC, the ſemidiameter of the wheel, reciprocally as the power E is to the power F, the firſt of which is applied in the direction

direction of the tangent of the axis, and the other in the direction of the tangent of the wheel, they will be in equilibrio. For AC may be conceived to be a lever, whose fulcrum is B, and whose forces applied at A and C are in the reciprocal proportion of their distances.

To this power may be referred the capstan or crane, by which weights are raised, the winch and barrel, for drawing water out of wells, and numberless other machines on the same principle.

The PULLEY is likewise explained on the principle of the lever. The line AC (fig. 16.) may be conceived to be a lever, whose arms AB and BC are equidistant from the fulcrum B. Consequently the two equal powers E and F (applied in the directions of the tangents to the circle in which the extremities move) will be in equilibrio. And the fulcrum B will sustain both forces.

But in fig. 17. the fulcrum is at C, therefore a given force at E will sustain in equilibrio a double force at F, for in that proportion reciprocally are their distances from the fulcrum. Whence it appears, that, considering

ſidering E as a force, and F as a weight to be raiſed, no increaſe of power is gained when the pulley is fixed (as in fig. 16.) but that a double increaſe of power is gained when the pulley moves with the weight (fig. 17.)

A combination of pullies is called a tackle, and a box containing one or more pullies, is called a block.

ADB (fig. 18.) is a tackle compoſed of four pullies; two of which are in the fixed block A, and the other two in the block B that moves with the weight F. Now, becauſe the rope is equally ſtretched throughout, each lower pulley will be acted upon by an equal part of the weight: and, becauſe in each pulley that moves with the weight a double increaſe of power is gained; the force by which F may be ſuſtained will be equal to half the weight divided by the number of lower pullies. That is, as twice the number of lower pullies is to 1, ſo is the weight ſuſpended to the ſuſpending force.

But if the extremity C (fig. 19.) be affixed to the lower block, it will ſuſtain half as much as a pulley; conſequently the analogy will

will then be, as twice the number of lower pullies, more 1 is to 1, ſo is the weight ſuſpended to the ſuſpending force.

This reaſoning depends on the equal tenſion of the rope, and is therefore concluſive only when the tackle is wrought by a ſingle rope. In the ſyſtem of pullies, (fig. 20.) the power increaſes in a geometrical ſeries whoſe common ratio is 2, and number of terms equal to the number of pullies. Thus, if a force be applied at A, it will be acted upon by half the weight F; if at B, by $\frac{1}{4}$; if at C, by $\frac{1}{8}$; and if at D, by $\frac{1}{16}$, &c. The reaſon of which is evident from what has been already ſaid.

It is evident, that in the compoſition of forces, the force produced is leſs than the ſum of the compounding forces; AD being always leſs than the ſum of AC and AB. On the contrary, in the reſolution of force, a gain of force is produced, which is exemplified in the following inſtance.

The rope EACBF (fig. 21.) is paſſed over the pullies A and B, and under the pulley C. Equal weights are ſuſpended at E and F, whoſe actions on C may be repreſented by

the equal lines CJ and CH. Reſolve theſe forces into CD, which will expreſs the force with which the two weights E and F tend to move C in the direction of the perpendicular, and which is leſs than the ſum of CJ and CH. Conſequently a weight G being applied at C, whoſe quantity is leſs than the whole quantity of E and F in the ſame proportion, will ſuſtain their effects, and remain in equilibrio. Therefore, if we conſider E and F, as producing by compoſition a force equal to G, a loſs of force enſues; and on the other hand, if G be conſidered as producing forces by reſolution equal to E and F, an increaſe of force is acquired.

The quantity of this increaſe or diminution is readily determined thus.

From J let fall the perpendicular JK upon CD, then CK will be the half of CD. And JC is half the ſum of JC and CH. Now, as the whole of that ſum is to CB, ſo is the ſum of the weights E and F to the weight G (for they reſpectively repreſent the forces of thoſe weights) and ſo is JC to CK. But JC is the ſecant of the angle formed between the

the rope AC and the perpendicular (CD) the line CK being radius. Therefore, as the ſecant of the angle formed between one of the ropes, and the perpendicular is to radius, ſo is the ſum of the weights E and F to the weight G.

The pulley or tackle is of ſuch general utility, that it is needleſs to point out any particular inſtance.

C H A P IV.

Of the inclined Plane, and of the Wedge.

THE INCLINED PLANE has in its effects a near analogy to the lever. Let AB be an horizontal plane on which the weight E is placed, and let ED repreſent the force exerted by the ſaid weight. AB may alſo be conceived to act as the arm of a lever, whoſe fulcrum is A. Let this lever revolve on its fulcrum from B to C, then the weight E will be found at e, and will act on the plane AC with an oblique force ed, equal and parallel to ED. Reſolve ed into

into e b and b d, and the force e b will be deſtroyed by the reaction of the plane. With the other force b d, the weight will proceed with an accelerated motion towards A. Whence it may be obſerved, that the inclined plane acting againſt e in the nature of a lever, deſtroys that force which is exerted in the direction of the tangent of its line of motion, and that the acting force in this inſtrument is that which in treating of the lever was rejected, as having no effect. The force with which any weight on an inclined plane tends downwards in the direction of the plane, is to the weight itſelf, as b d to d e. Or as e F to A e, which is the ratio of the length of the plane to its height, becauſe the triangles b e d and FeA are ſimilar. But eF is to Ae as the ſine of the angle the inclined plane makes with the horizon is to radius. Therefore, as the ſaid ſine is to radius, ſo is the force tending downwards in the direction of the plane to the weight. And by reverſing the proportion, the angle of inclination and weight being known, the tendency in the direction of the plane may be found.

This

This inſtrument is not much uſed in its ſimple form.

If it be required to ſhew what force in the direction e p parallel to AB (fig. 23.) will ſuſtain the weight e in equilibrio. Set off e m equal to b d, which will repreſent its force or tendency in the direction of the plane and equal, but on the contrary ſides ſet off e n, which will repreſent the force that applied in the oppoſite direction will ſuſtain the weight in equilibrio. Draw n p perpendicular to AC and e p parallel to AB, interſecting n p in p, e p will be the force required; for it is compoſed of e n and n p, and n p being perpendicular to the direction of the motion of e avails nothing. Join p d and this laſt found force is to the whole weight of e, as p e to e d, or as eF to FA, (which is the ratio of the perpendicular height of the plane to its horizontal baſe) for the triangles ped and eFA are ſimilar. And ſince the mutual effects of bodies on each other depends not upon their abſolute, but relative motion, it is evident that the ſame force e p, which ſuſtains e on the fixed inclined plane CAB applied in the contrary

direction

direction would (if the plane be ſuppoſed moveable in the direction of its baſe AB, and the body e fixed by the application of an obſtacle qr) ſuſtain the effort with which the ſaid body tends to impel the plane from e towards p.

The WEDGE is compoſed of two inclined planes joined together at their common baſe, in the direction of which the power is impreſſed.

Let ABC (fig. 24.) repreſent a wedge, whoſe vertex A is inſerted between the two bodies D and E, which being fixed in poſition, reſiſt in a certain degree any force which tends to ſeparate them. This reſiſtance is (like the weight in the inclined plane) perpendicular to the baſe AF, and the power (or force employed to overcome it) is impreſſed as was juſt mentioned, in the direction of the ſaid baſe. Therefore, by the property of the inclined plane, the force required to keep one half CFA of the wedge in equilibrio with the preſſure of the body D, is to that preſſure as CF to FA. But as the preſſure on the other half of the wedge is equally ſtrong, a double force will be required to preſerve the

the equilibrium, that is, a force as CB to FA. Or, in general terms; in any wedge, as the line CB, joining the two equal ſides AB and AC, is to the diſtance between the vertex A, and the middle point F of CB, ſo is the force impreſſed to the reſiſtance in D and E.

This inſtrument is commonly uſed in cleaving wood, and was formerly applied in engines for ſtamping watch plates. The force impreſſed is commonly a blow, which is found to be much more effectual than a weight or preſſure. This difference is accounted for, by ſuppoſing that the tremulous motion produced by the ſtroke, conſiderably diminiſhes the very great friction at the ſides.

Knives, ſaws, and all cutting inſtruments may be referred to the wedge.

CHAP. V.

Of the Screw, and of Mechanical Engines in general.

THE SCREW is compoſed of two parts, one of which is called the ſcrew, and conſiſts of a ſpiral protuberance, called the thread, which is wound or wrapt round a cylinder, ſo that each ſucceſſive turn may be parallel to the former; the other part, called the nut, is perforated to the dimenſions of the cylinder, and in the internal cavity is cut a ſpiral groove which is adapted to receive the thread.

Let AB (fig. 25.) repreſent the ſcrew perpendicular to the horizon, and CD the nut. Then the ſcrew being fixed, the nut may be conſidered as a weight to be raiſed by ſliding it up the thread, which anſwers in its effect to an inclined plane. For the thread having the ſame inclination throughout, differs in no reſpect, as to power, from an inclined plane of the ſame length and height. Conſequently a force applied horizontally to the nut,

nut, will ſuſtain it when that force is to the whole weight of the nut, as the perpendicular diſtance between any two contiguous threads is to the circumference of the cylinder. And a force applied in the direction of the threads of the ſcrew will ſuſtain the weight, when it is to the weight as the perpendicular diſtance between any two contiguous threads is to the length of one ſpiral revolution round the cylinder.

This engine is never uſed but in conjunction with the lever, as DE, in which caſe the powers laſt found are increaſed in the proportion, as the diſtance of E from the axis of motion is to the ſemidiameter of the cylinder.

The ſcrew is of vaſt uſe for compreſſing bodies together, as paper, &c. and is the principal organ in the inſtrument for ſtriking coins.

Thus much for a ſhort account of the effects of forces applied to mechanical inſtruments. It is eaſy to conceive, that when forces are in equilibrio, if the leaſt addition be made to one of them, it will preponderate and overcome the effort of the other. But

the want of a perfect poliſh or ſmoothneſs in the parts of all inſtruments, and the rigidity of all ropes, which increaſes with the tenſion, are great impediments to motion, and in compounded engines are found to diminiſh about one fourth of the effect of the power.

The properties of all the mechanical powers depending, as has been ſhewn, on the laws of motion laid down in the beginning of this treatiſe, and the action, or tendency to produce motion, of each of the two forces, being applied in directions contrary to each other, the following general rule for finding the proportion of the forces in equilibrio on any machine will require no proof.

If two oppoſite forces be applied to the terms * of any mechanical engine, in the direction of the lines, in which, by the conſtruction of the engine, the ſaid terms would move; and the intenſities of the forces be to each other reciprocally as the ſpaces which the terms when in motion would deſcribe in the ſame time: then thoſe forces will be in equilibrio.

* *Term*, quaſi *terminus*, a limit, is here uſed to expreſs thoſe parts of an engine at which the forces are applied.

Suppoſe

Suppofe the forces to be weights, and the fame may be expreffed more concifely thus.

If two weights applied to the terms of any mechanical engine be to each other in the reciprocal proportion of the perpendicular fpaces which would be defcribed by each when in motion; they will be in equilibrio.

Whence it may be obferved, that in all contrivances by which power is gained, a proportional lofs is fuffered in time. If one man by means of a tackle can raife as much weight as ten men could by their unaffifted ftrength, he will be ten times as long about it.

It is convenience alone, and not any actual increafe of force which we obtain from mechanics. The following inftance may ferve to illuftrate this matter.

Suppofe a man at the top of a houfe draws up ten weights, one at a time, by a fingle rope, in ten minutes. Let him have a tackle of five lower pullies, and he will draw up the whole ten at once with the fame eafe as he before raifed up one; but in ten times the time, that is, in ten minutes. Here then we fee the fame work is done in the fame time,

 whether

whether the tackle be uſed or not: but the convenience is, that in caſe the whole ten weights be joined into one, they may be raiſed with the tackle, though it would be impoſſible to move them by the unaſſiſted ſtrength of one man.

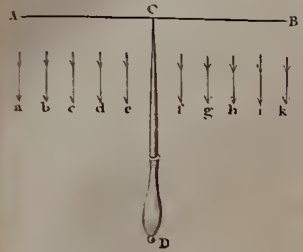
Or, ſuppoſe, inſtead of ten weights, a man draws ten buckets of water from the hold of a ſhip in ten minutes, and that the ſhip being leaky, admits an equal quantity in the ſame time. It is propoſed, that by means of a tackle, he ſhall raiſe a bucket ten times as large. With this aſſiſtance he performs it, but in as long a time as he was drawing the ten, and therefore is as far from gaining on the water in the latter caſe as in the former.

Since then, no real gain of force is acquired from mechanical contrivances, there is the greateſt reaſon to conclude, that a perpetual motion is not to be made. For in all inſtruments the friction of their parts and other reſiſtances do continually deſtroy a part of the moving force, and at laſt put an end to the motion.

CHAP.

p 7. Vol. I.

No. II. Center of Gravity. Fig 26 p. 72.



Center of Gravity. Fig. 27. p. 73.

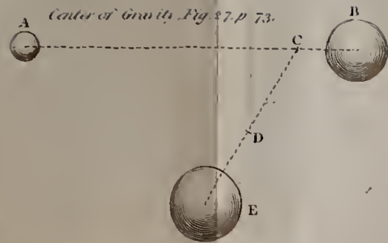
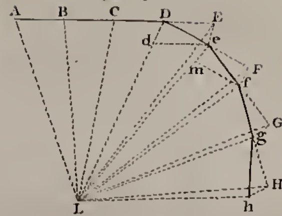
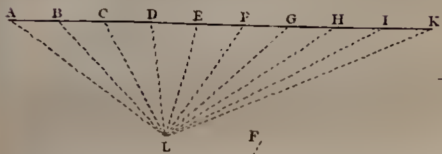


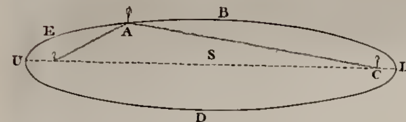
Fig 29. p. 79.



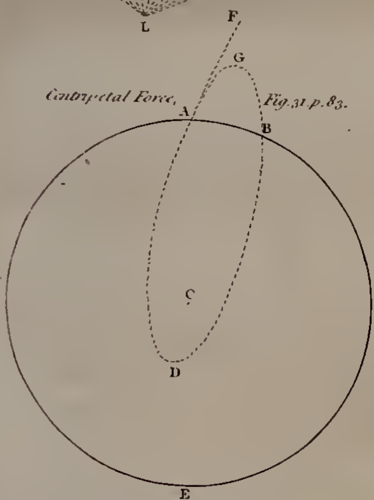
Centripetal Force. Fig. 28. p. 79.

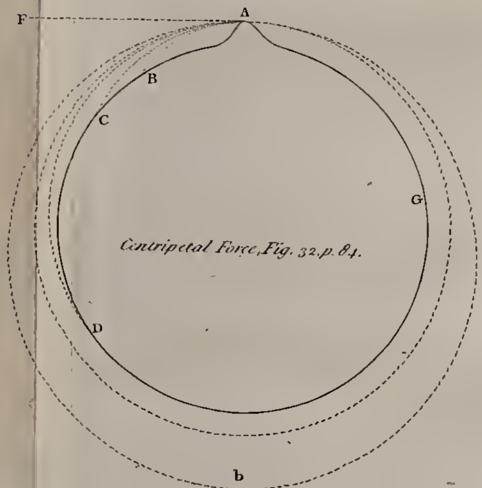


Ellipsis. Fig. 30. p. 83



Centripetal Force, Fig. 31. p. 83.





Centripetal Force, Fig. 32. p. 84.

CHAP. VI.

Of the Center of Gravity.

THAT action and reaction are equal and contrary in all cafes of motion produced by impulfe, is fufficiently evident. It will likewife appear, that the fame law obtains in thofe motions which are produced by * attraction.

Suppofe two bodies, A and B, mutually attracting each other, be prevented from coming into contact by an obftacle interpofed. If either of the bodies, for inftance, A, be more ftrongly attracted towards B, than B towards A, the obftacle will be more ftrongly acted upon by the preffure of A than by that of B; and therefore will not remain at reft. The ftronger preffure will prevail, and will caufe the two bodies together with the obftacle to move in a right lined direction towards that fide on which B is placed, with a motion uniformly accelerated for ever.

* It is not here afferted, that attraction is not produced by impulfe.

Which is absurd and contrary to Law I. Therefore the bodies do equally press the obstacle, and consequently are equally attracted towards each other.

By the same argument, it is proved, that the gravitation between the earth and its parts is mutual and equal.

Let AB (fig. 26.) represent a long slender body of an inconsiderable thickness, which is attracted by another body in the direction of the small arrows, a b c d, &c. Then the motion of AB will be the sum of the motions of all the parts situate between A and B. Interpose the pointed obstacle CD, and AB may be considered as a lever, C being the fulcrum. Consequently, if C be so placed that the parts between A and C may be in quantity and distance from the fulcrum equipollent to those between C and B, the whole body will rest in equilibrio on the point C. This point is called the center of gravity.

The thickness of AB being inconsiderable, the point C may be esteemed as the center of gravity, but is not so when the thickness is taken into the account. The above explanation is only to shew that when we speak of the

the whole attractive force of a body being collected in its center (e. g. the center of the earth) it is not to be fuppofed that any real power, or, as it were, magic force, exifted in that center. In like manner the body AB ceafes to move, not immediately becaufe its center of gravity is fuftained, as if the caufe of motion exifted in that center alone, but becaufe by the nature of the lever, the forces on the fide CB are made to counteract and deftroy thofe on the fide CA.

The center of gravity may be defined to be a point about which all the parts of a body or bodies are in equilibrio.

Therefore, the center of gravity of two bodies, A and B, (fig. 27.) will be a point C, in the right line which joins their centers of gravity, which is diftant from the center of each body in the reciprocal proportion of their maffes; that is, AC : CB : : B : A. And the center of gravity of three bodies, fuppofe A, B and E, will be found at D in the line CE which joins the center of gravity of E with the point C. CD being to DE reciprocally as the fum of the maffes of A and B is to the

mafs

maſs of E. For it is eaſily proved, ſuppoſing the lines to be levers, that the bodies A and B will equilibrate about the point C, which, as the fulcrum, will ſuſtain both their forces; and alſo, that the body E will equilibrate with the force ſuſtained at C; D being the fulcrum. In this manner the center of gravity of any ſyſtem of bodies may be found.

The common center of gravity of two or more bodies, does not change its ſtate of motion or reſt from the mutual actions of the bodies upon each other; and therefore, the common center of gravity of all bodies mutually acting upon each other, is either at reſt or moves uniformly in a right line, actions and impediments from without being excluded.

If the bodies A and B act upon each other, the motion produced in each will be equal, and the ratio of CA to CB will remain the ſame, whether they approach to or recede from each other. Conſequently the ſtate of C will not be changed by their mutual actions. If the third body E be added to the ſyſtem, the center D for the ſame reaſon will not be changed, as to its ſtate of motion or reſt,

reſt, whether E acts upon C or not, and ſo on for any number of bodies.

If two bodies move uniformly in right lines, their common center of gravity will either be at reſt, or will move uniformly in a right line; and the ſame is likewiſe true of the center of gravity of three bodies, for the center C of any two of them may be conſidered as one body. Therefore, if C and E be in motion, the common center D will either be at reſt, or will move uniformly in a right line. By this means, the ſame may be ſhewn of any number of bodies.

Since then the ſtate of the center of gravity of any ſyſtem of bodies, as to reſt or uniform direct motion, is not affected either by the motions or mutual actions of the bodies of which it is compoſed, external actions or impediments being excluded, it is plain that the ſame law holds good in the motion of a ſyſtem of bodies as is obſerved by a ſingle body. For the progreſſive motion of a ſingle body or of a ſyſtem of bodies, muſt be eſtimated by the motion of the center of gravity.

Hence

Hence it is that the center of gravity of the earth is not affected by the motions on its surface, or in its bowels. When a projectile, a cannon ball for instance, is thrown upwards, the projecting force reacting on the earth, causes it to move in the contrary direction; but as the * motions are equal, the center of gravity remains the same.

The motions and actions of bodies upon each other in a space that is carried uniformly forward, are the same as if that space were at rest.

For the motions and actions of bodies upon each other depend on their relative motion, the velocity of which is the sum of their absolute velocities, when they are moved in opposite directions, or their difference when they move in the same direction. And this sum or difference is not altered by an equal velocity impressed on all the bodies in the same or a parallel direction (as in the present case): since, when two bodies move in con-

* Not the velocities or spaces described. For the space described by the earth is less than that described by the projectile in the same proportion as the mass of the projectile is less than that of the earth.

trary

trary directions, in a ſpace carried uniformly forward, the velocity added to that body, with whoſe motion the * motion of the ſpace conſpires, is exactly equal to the velocity deſtroyed in the other body, whoſe motion is oppoſed by that of the ſpace; and when the bodies move in the ſame direction, an equal velocity being added to or deſtroyed in both, the difference is likewiſe unaltered. This is likewiſe confirmed by daily experience, motions performed on board a ſhip under ſail are the ſame as if the ſhip were at anchor; except ſo far as they may be diſturbed by the irregular toſſing of the waves, which affects them ſucceſſively, as much in one direction as another. A fleet of ſhips carried by an uniform current, either preſerve the ſame relative poſitions, or approach to or recede from each other in the ſame manner as they would if no ſuch current exiſted. And the

* *Space* being in its own nature immoveable, the expreſſion is here improper; but it conveys a clearer idea of the propoſition, though we can form no idea of bodies included in a ſpace being acted upon by that ſpace. The ſpace here mentioned is merely ideal, may be called *relative*, and is defined to be a *moveable dimenſion*.

motions

motions of bodies at the ſurface of the earth are no otherwiſe affected by its revolution on its axis, than as the revolution is not rectilinear, the effects of which, though conſiderable, are not enough ſo to fall under common obſervation.

This propoſition is likewiſe true, if the motion of the ſpace be uniformly accelerated, or which is the ſame thing, if all the bodies be conſtantly acted upon by parallel forces which act equally, according to their maſſes, on each of them.

For ſuch forces will cauſe all the bodies to move with the ſame acceleration, and to deſcribe equal ſpaces in the ſame direction with each other. They will not therefore change their relative motions or ſituations.

CHAP. VII.

Of the Motion of a Body, which is acted upon by a centripetal Force.

IF a body at A (fig. 28.) be carried with an uniform direct motion towards K, and rays be drawn from the equidistant points A, B, C, D, E, &c. to any point L without the line AK, the areas ALB, BLC, CLD, DLE, &c. will be equal to each other *.

And these areas which are described in equal times, will not be altered by any centripetal force acting on the body A, and impelling it towards L.

Suppose the body A, (fig. 28.) to describe the equal spaces AB, BC, CD, and consequently with respect to the point L, the equal areas ALB, BLC, CLD, in equal times. Let a centripetal force be impressed at D, which would cause it to de-

* This reasoning depends on that well-known proposition (38. e. 1.) that triangles constituted upon equal bases, and between the same parallels are equal to one another.

ſcribe the ſpace Dd in the ſame time as DE, (which is equal to DC, &c.) Complete the parallelogram DdeE, and at the end of the time the body will be found at e; having deſcribed the diagonal De. Then will the triangle DeL be equal to DEL, for they ſtand on the ſame baſe DL, and between the parallels DL and Ee. Continue eF equal to De, and the area eFL will be equal to DeL; eF repreſenting the ſpace which would be deſcribed in the ſame time as De, if no new impulſe were given at e. Let a force e m be impreſſed at e, and by the ſame proceſs it is proved, that efL is equal to eFL. The like may be proved of the triangles fgL, ghL, &c.

Since therefore any ſingle impulſe can only alter the velocity and direction, but never affect the area deſcribed, it is plain that any number of ſucceſſive impulſes will likewiſe have no effect on the area. Suppoſe the number of impulſes to be infinite, or, in other words, let a force directed to the center act continually on the body, and a polygon with an infinite number of ſides, that is

to

to ſay) a curve, will be deſcribed, whoſe radius accompanying the moving body, will deſcribe or ſweep over equal areas in equal times.

And converſely, if a body revolve about a point, ſo as to deſcribe a curve, whoſe radius accompanying the motion, does ſweep over equal areas in equal times, the centripetal force which deflects the motion from a right line, is directed to that point.

But no inſtance of a centripetal force directed to an immoveable point is found in nature. Bodies attract one another, and that mutually. Therefore, if one body revolves about another, this laſt will not remain at reſt, but will revolve in a * ſimilar curve about the common center of gravity, as will alſo the firſt body. That is to ſay, if the center of gravity be at reſt; the two bodies will abſolutely move in ſimilar curves about that center, and relatively about each other in curves ſimilar to thoſe laſt mentioned. And the time of a periodical revolution will be the ſame in both caſes.

* Principia. 57. l. 1.

Theſe motions will not be altered, if the center of gravity be ſuppoſed in motion.

Therefore, when we ſpeak of the orbits and periodical revolutions of bodies, we may in general regard one of the bodies as ſtationary, and the other as revolving round it.

If a body revolve round a center in an orbit which is not circular, it is plain, that to deſcribe equal areas in equal times, it muſt move ſwifter when near the center than when more diſtant; and it is likewiſe evident, that when the velocity, and conſequently the tendency to fly off in a tangent is increaſed, a greater centripetal force will be required to retain it in its orbit.

From the properties of the ellipſis it is demonſtrated, that a body revolving in that curve, whoſe centripetal force tends to one of its foci, muſt in any part of its orbit be attracted towards that focus, by a force which is reciprocally as the ſquare of its diſtance.

A very complete and clear idea of the ellipſis may be had from the common way of deſcribing it; if a thread CAC be faſtened by its

its ends at the points CC, and a pointed inſtrument be inſerted in the bight or bend at A, and moved towards B or E, keeping the thread at full ſtretch, it will in one revolution deſcribe the ellipſis ABDE. CC are called the foci. (See fig. 30.)

To illuſtrate this doctrine of revolving bodies, we may obſerve, that as gravity conſtantly acts on all bodies in the vicinity of the earth, attracting them towards its center, every projectile, which is not thrown in the line of the perpendicular, may be conſidered as a body revolving about that center; and if its orbit be not ſufficiently large to contain or circumſcribe the body of the earth, it will be interrupted in its courſe, and remain at reſt ſomewhere on the ſurface. Thus let ABE (fig. 31.) repreſent the earth, whoſe center is at C; then if a body be projected from A in the direction AF, it will by the action of the centripetal force be deflected into the curve AGB, and will remain at reſt at B, being prevented from deſcribing the whole orbit AGBDA, by the body of the earth, which interrupts its courſe at B. But the part AGB of the elliptical

orbit of a projectile is ſo ſmall, in compariſon to that part which is not deſcribed, that it may without any ſenſible error be conſidered as a parabola, except ſo far as the reſiſtance of the air, which is not here regarded, makes it fall ſhort of B, by deſtroying part of its motion.

The orbit AGBDA, of which the parabola is part, would have been deſcribed upon the ſuppoſition, that the attraction towards the center continued to obſerve the ſame law within as without the ſphere. But this ſuppoſition, however, is not true; for a ſphere of uniform denſity, compoſed of particles which attract each other with forces reciprocally as the ſquare of their diſtances, will attract bodies without its ſurface according to the ſame law; relation being had to its center. But the centripetal forces of bodies placed within the ſphere, will be directly as their diſtances from the center *.

Let the circle BCDG (fig. 32.) repreſent the earth. From the top of the mountain A, let a body be projected in the horizontal direction AF, with a force that will carry it to B on the

* Principia, 80. l. 1.

ſurface.

ſurface. Imagine it to be projected in the ſame direction with a ſtill greater force, and it will be carried to C. A ſtill greater increaſe of force will carry it to D. And a yet greater augmentation will carry it round the earth to A, where it will proceed with a velocity equal to that with which it was firſt projected, and by conſequence (the reſiſtance of the air being diſregarded) will revolve in that orbit for ever. But if the projectile force be ſtill more increaſed, it will deſcribe the ellipſis AbA with an unequable motion; ſlower at b and ſwifter at A, and continue to revolve for ever in that orbit.

If gravity acts in the diſtant ſpaces of the heavens inverſely according to the ſquares of the diſtances, it will be eaſy to apply this to the motions of the celeſtial bodies. This will be proved hereafter, but in the mean time it is neceſſary, that the appearances ſhould firſt be deſcribed before an explanation of them can be given.

BOOK I.

SECT. III.

Of Astronomy.

CHAP. I.

Of the System of the Universe.

IN the early ages of the world, it is more than probable that the ſciences originated from the wants of mankind. The mechanic arts were invented to forward the labours of agriculture, and thoſe works which are neceſſary to render life comfortable. Geometry was invented for the purpoſe of marking the limits or quantity of lands; and an accurate obſervation of the returns of the ſeaſons was required,

required, that the proprietor might with certainty know when to expect his crop. Hence the origin of aſtronomy. Perhaps this ſcience might have been long applied to no other uſe than that of dividing time, if the natural fertility of the human invention had not attributed to the heavenly bodies the function of ſuperintending the fates of men. The conſciouſneſs of the exiſtence of a deity being the immediate conſequence of the conſciouſneſs of ſelf-exiſtence, it was natural to wiſh for the knowledge of his intentions and our duty. Whether reaſon, unaſſiſted by revelation, be adequate to the taſk of gratifying this wiſh, is a queſtion foreign to our preſent purpoſe; but certain it is, that the ancients, inſtead of enquiring with that coolneſs and caution which are ſo neceſſary in any reſearch whatſoever, did on the contrary give rein to their imagination, and formed a ſyſtem of theology, which, though highly inconſiſtent, was almoſt univerſally received till the introduction of Chriſtianity. Inſtead of attending to the idea of *One*, omnipreſent and omniſcient, they invented an innumerable hoſt of ſubordinate

deities, each of whom governed in his reſpective province. The ſeven erratic bodies, viz. the Sun, Moon, Saturn, Jupiter, Mars, Venus, and Mercury, were ſuppoſed to be under the immediate direction of as many gods of different tempers and diſpoſitions. Plants, animals, and even men were claſſed out to each of theſe gods, and a chimerical ſcience was laid down for the prediction of future events, from the relative ſituations or aſpects of the celeſtial bodies. This was called aſtrology, and is not at this day entirely exploded. A motive ſo important and gratifying to the anxious curioſity of man could not fail to produce a conſtant obſervation of theſe aſpects, and by that obſervation, the knowledge of aſtronomy had made a conſiderable progreſs, while more obvious ſciences were yet in their infancy.

By the earlieſt accounts it appears probable, that the orientals were firſt acquainted with the true ſyſtem of the world; Pythagoras having obtained that knowledge during his travels in India, which he afterwards taught in Magna Græcia. Let us paſs by the various

rious and intricate ſchemes by which philoſophers attempted to reſolve the celeſtial appearances, till the ancient ſyſtem of the world was revived by * Copernicus, whoſe name it has ever ſince retained. Let us ſuppoſe ourſelves in the ſituation of the oriental ſages, to whom the firſt diſcovery is attributed, and by tracing the ſteps by which it was made, we ſhall exhibit a clear idea of it, at the ſame time that we expoſe the proofs by which we are induced to receive it as truth.

The firſt and moſt obvious phenomenon that preſents itſelf to obſervation, is the apparent diurnal motion of the heavens, by which the ſun, moon, and ſtars are ſeen to riſe and ſet. This motion was ſoon obſerved to be ſubject to ſeeming irregularities. If its period was eſtimated from ſunriſe to ſunriſe, a little time evinced, that the ſun did not always riſe on the ſame azimuth, nor remain above the horizon ſo long in winter as in ſummer. The moon was ſtill

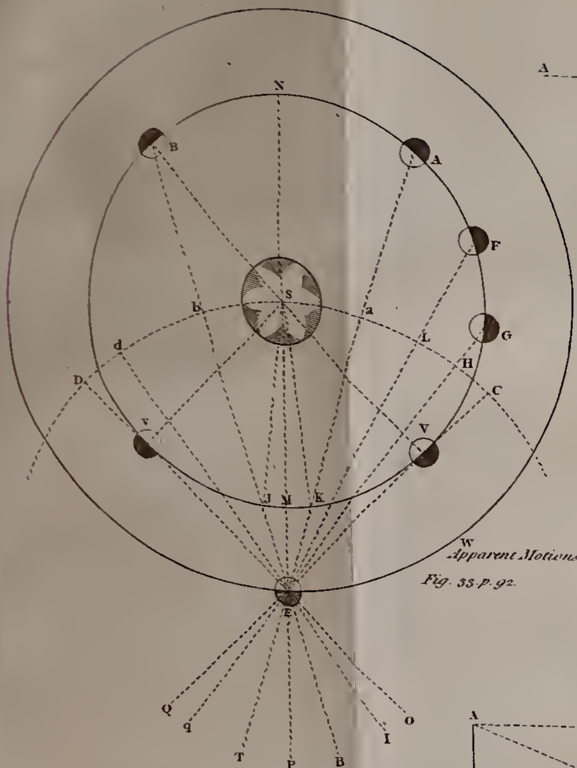
* A. D. 1543, the year in which he died. After ſuppreſſing his book de Revolutionibus Orbium cœleſtium for more than ſix-and-thirty years, it was at length publiſhed, and a copy brought to him a few hours before his death.——Gaſſendus in vita Copernici.

leſs

leſs adapted to the purpoſe of determining this period, her variations being in every reſpect more conſpicuous. The fixed ſtars remained which appeared indeed to riſe and ſet regularly, but yet in a period ſhorter than the natural day; for thoſe ſtars, which at a certain time of the year were ſeen to riſe at midnight, were found to make their appearance early in the evening, after the ſpace of three months was elapſed. It was therefore to be determined, which of thoſe motions ought to be regarded as the motion of the heavens; and it was much more obvious and intelligible, to ſuppoſe, that the ſun, by a relative motion to the eaſtward with reſpect to the fixed ſtars, ſhould make the days ſomewhat longer than the real time of a revolution, than that all the ſtars ſhould conſtantly move with a velocity greater than that of the heavens. To determine this relative path of the ſun was not difficult. By the ſhadow of a perpendicular ſtaff or other equivalent inſtrument at mid-day, his varying declination towards the north or ſouth might be known, and the afore-mentioned advance in the riſing of the ſtars would mark

his

[illegible]
N°. I.



Apparent Motions of the Planets
Fig. 33. p. 92.

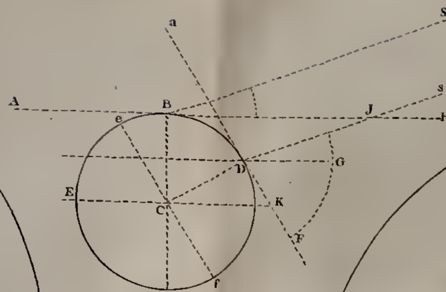
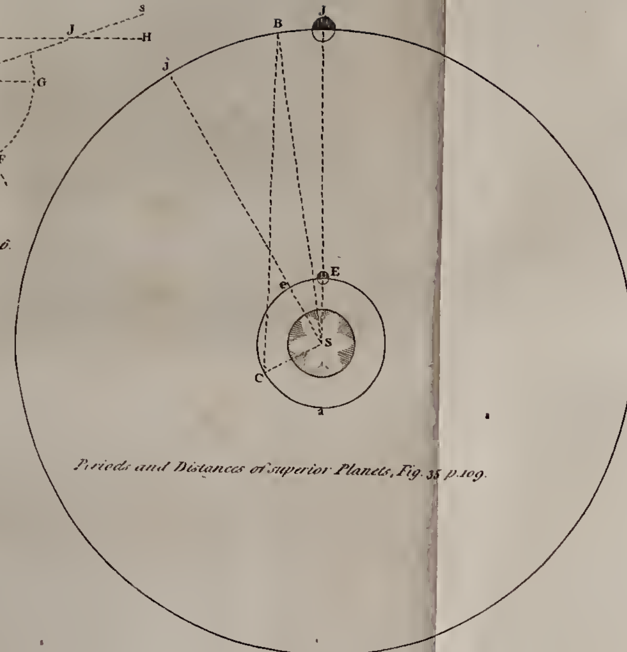
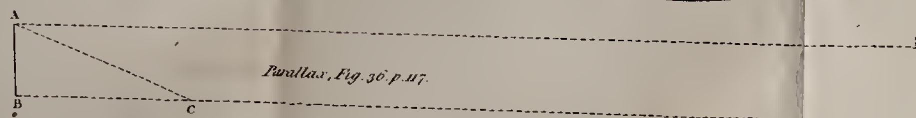


Figure of the Earth, Fig. 34. p. 96.



Periods and Distances of superior Planets, Fig. 35 p. 109.



Parallax, Fig. 36. p. 117.

his difference in right aſcenſion. By this or ſome ſuch method, it was diſcovered, that while the fixed ſtars riſe and ſet, each on its proper azimuth, without varying their relative poſitions; the ſun, by deſcribing annually a circle towards the eaſt, which was inclined to the direction of its daily courſe in an angle of 23 $\frac{1}{2}$ * degrees, did occaſion all the difference of ſeaſons, length of days, &c.

In noting theſe appearances, the obſerver would of courſe ſelect the brighteſt ſtars as objects of his attention. Thoſe are the planets, and conſequently their motions could not long remain unnoticed. The planet Venus eſpecially, receding from the ſun to the eaſtward, would appear as an evening ſtar in the weſt after ſunſet; would diſappear on its re-approach to it, and afterwards be ſeen at a, nearly, equal diſtance to the weſtward, and riſing before the ſun, become a morning ſtar. The ſlowneſs of its apparent motion

* Theſe terms are explained at ch. 12 of this ſection, which ſee.——Every circle is ſuppoſed to be divided into 360 parts, which are called degrees.

near

near its greateſt elongation or angular diſtance from the ſun, would ſhew that that motion was performed in an orbit, in the center of which the ſun was placed; and the ſhort time employed in paſſing from its greateſt elongation eaſtward to its greateſt elongation weſtward, when compared to the time of its courſe between the ſame elongations in the contrary direction, would evince that its revolution was made from weſt to eaſt. The proportion between its diſtance from the ſun, and that of the ſun from the earth, would be found from the quantity of its greateſt elongation.

To illuſtrate this. Let S (fig. 33.) repreſent the ſun, E the earth, ABvKVHF the orbit of Venus, CHLaSbD part of the ecliptic or ſun's annual path. Then to a ſpectator at E, ſituate nearly in the plane of the ſaid orbit, the planet when at B will be referred to the point b in the ecliptic; and when by its regular motion in its orbit, it has deſcribed the arc Bv, it will appear to have deſcribed with an irregular motion the arc bD. When at v, it will appear ſtationary at D, and after a little time

time begin to move back from D to b: for after defcribing the arc vJ, it will again be feen at b. Continuing its courfe, it will arrive at V, having apparently paffed through the arc bC. At V it will again become ftationary, and afterwards move to G, F, A, &c. which will be reprefented by their correfponding points in the ecliptic. Now fince the motion as feen from the earth, is that which appears in the ecliptic, and fince the apparent motion from b to D, may as well be produced by a real motion from J to v, as by one from B to v, it remains to be determined in what direction the real motion is made by which the apparent motion is produced. Becaufe EC and ED are tangents to the orbit, the points D and C, which correfpond with the pofitions v and V, are thofe of its greateft elongations, and becaufe the arc vV, which is paffed over in the inferior part of the orbit between the two greateft elongations, is much lefs than the fuperior arc VABv, which is paffed over between the fame elongations, it is plain, that when the planet is in the inferior part of the orbit, the fpace CD will be performed in much

leſs time than when it is in the ſuperior part. It is alſo evident, when the planet moves in the ſuperior part of its orbit, that the apparent motion in the ecliptic has the ſame direction as the real motion. Therefore, ſince we have a criterion to diſtinguiſh the motion in the ſuperior from that in the inferior part, we can eaſily determine the direction of the motion in its orbit, which is proved to be from weſt to eaſt.

The diſtance of Venus from the Sun, in proportion of that of the Sun from the earth, is determined from its greateſt elongation; thus draw the line VS, which will be at right angles to the tangent VE, then in the right angled triangle VES, by the rules of plain trigonometry,

As radius
Is to the ſun's diſtance ES,
So is ſine of the angle of greateſt elongation VES,
To the diſtance of Venus from the ſun VS.

By ſimilar obſervations on the planet Mercury, it is determined that his revolu-

tions are performed round the ſun in like manner, and accompanied with circumſtances of the ſame nature as Venus.

C H A P. II.

Of the Figure and Motion of the Earth.

FOR the ſake of conciſeneſs, we have not hitherto conſidered the effects which the ſun's annual motion in the ecliptic has upon the apparent motions of the planets, though it is very conſiderable. Neither have we determined whether this apparent annual motion be the conſequence of a real motion of the ſun about the earth, or of the earth round the ſun. The cœleſtial phenomena may be explained either way, but in a much more ſimple and intelligible manner by the latter ſuppoſition. The apparent motions of the planets, Mars, Jupiter, and Saturn are ſo remarkably affected by this annual motion, that we cannot avoid having recourſe to it in our explanation.

We

We ſhall therefore previouſly give an account of the figure of the earth, and the reaſons on which the *ſuppoſition* of its motion is founded. The *proof* will come more properly when we treat of the phyſical cauſes of theſe motions. At preſent we only deſcribe appearances, and draw plain inferences from them.

The fixed ſtars being claſſed into conſtellations, and their relative ſituations known, an obſerver would ſoon perceive that their diurnal revolutions were performed round an axis, obliquely ſituated with reſpect to the horizon; one of its extremities or poles being above the horizon to the * north, and the other as far below it to the ſouth, and conſequently inviſible. By travelling to the northward, the north pole would become more elevated, and that exactly in proportion to the ſpace travelled over; whence follows the concluſion, that the earth is round or ſpherical. Let the circle EBD, (fig. 34.) repreſent a ſection of the earth, AH the ſenſible horizon, EK the rational horizon parallel to it. A ſpectator

* Suppoſing the obſerver to be in north latitude.

at

at B ſees the * pole ſtar at S (elevated above the horizon in the angle HBS) ſo far diſtant that any lines drawn from the earth to it may be reckoned parallel. Then, if the earth be flat or plane, and the ſpectator travel northward from B to J, he will ſtill ſee it in the ſame elevation, for the angle sJH is equal to the angle SBH, becauſe SB and sJ are parallel. But if the earth be ſpherical, the elevation of the north pole, by travelling northward, will be always in proportion to the diſtance travelled over.

For, let the ſpectator travel from B to D, over the arc or ſpace BD, his ſenſible horizon will then be repreſented by the line aF, and his rational horizon by ef; he will ſee the ſtar in the direction Ds parallel to BS, and its altitude above the horizon will be the angle sDF. Draw the line DG parallel to BH, and the angle sDG will be equal to the angle SBH, and the angle GDF will be the increaſe of altitude. Now, becauſe Cf and DF are parallels, as are like-

* There is no ſtar which is ſituated at the pole. The ſtar α in Urſa Minor, which is called the pole ſtar, is about $2\frac{1}{2}$ degrees diſtant from it.

wise CK and DG, the angles KCf and GDF are equal; and because the angles KCf and BCD are both less than a right angle, by the deduction of the common angle DCK they also are equal. Whence the angle GDF is equal to the angle BCD. But the angle BCD (and consequently the angle GDF) is ever in proportion to the length of the arc BD, which subtends it. The arc BD is the distance travelled over. Therefore, if the earth be a sphere, the elevation of the pole which is gained by travelling towards it, is always in proportion to the distance travelled over. This is found to be true, in fact, therefore, as above asserted, the earth is spherical.

Hence, if the length of the arc BD be measured, and its quantity in degrees known by observation on a star, the length of the whole circumference of the earth may be found by the proportion. As the quantity of degrees is to the length measured, so is the whole circumference, or 360 degrees to its length.

The modern circumnavigation likewise proves the sphericity of the earth, for by sailing continually eastward, or continually

westward,

weſtward, veſſels arrive again at the port from whence their firſt departure was taken.

Alſo, in an eclipſe of the moon, the ſhadow of the earth is always projected in a circular form. Now, it is evident, that the body whoſe ſhadow is in all poſitions a circle, muſt itſelf be a globe.

Unfurniſhed with the proofs, which the ſagacity and more accurate obſervations of later ages have afforded, the ancients could not adduce thoſe reaſons for the earth's motion, which depend on the general laws of motion, and the nature of gravity. Without doubt they had recourſe to thoſe which depend on the moral fitneſs of things. They were perſuaded that the wiſdom of the *Almighty* had created every thing in the beſt manner poſſible, and therefore, that when an effect could be as well produced by ſimple cauſes as by complicated ones, the obſerver of nature ought to attribute it to the former. They ſaw the two planets, Mercury and Venus revolving round the ſun in orbits, whoſe radii were leſs than the diſtance between the ſun and the earth: the ſuperior planets, Mars, Jupiter, and Saturn, were

alſo obſerved to move in orbits about the ſun, but at greater diſtances than that between the ſun and earth. If the ſun were ſuppoſed to move in the ecliptic, it muſt carry the orbits of theſe bodies along with it, and conſequently their abſolute motions muſt be very complicated; but if the earth be ſuppoſed to deſcribe an orbit round the ſun, between Venus and Mars, the abſolute motions are ſimple and natural, and a beautiful uniformity prevails throughout the ſyſtem.

The annual motion of the earth being allowed on this principle, its diurnal motion would follow by the ſame argument; it being much more reaſonable and conſiſtent to ſuppoſe, that the earth by a daily revolution on its own axis from weſt to eaſt, ſhould occaſion the apparent motion of the cœleſtial bodies, than that thoſe bodies ſhould, beſides their other various motions, have that aſtoniſhing velocity which a real diurnal motion ſhould produce. The objections which common obſervers might make, would be eaſily diſproved by men whoſe penetration was capable of going thus far. From the

the obſervations by which the ſpherical form of the earth was diſcovered, they would alſo gather, that bodies fell not abſolutely down with reſpect to ſpace itſelf, as was imagined, but always in a line directed towards the center of the earth, and conſequently that no danger of bodies falling off would ariſe from its continual change of poſition. The inſtances of ſhips carried by the tides in calm weather, would likewiſe ſhew, that the relative motions or poſitions of bodies are not changed by an equal velocity given to them in the ſame parallel direction.

C H A P. III.

Of the mutual Appearances of the ſuperior and inferior Planets.

THAT the planets Mars, Jupiter, and Saturn do revolve in orbits, which include the orbit of the earth, is evident, becauſe they are frequently ſeen in the part of the ecliptic directly oppoſite to the ſun; and that theſe orbits do reſpect the ſun, as a

center appears as well from thoſe oppoſitions which happen in every part of the ecliptic, as from their unequable apparent motions, which are explained by referring them to that center.

We have conſidered the apparent motions of the inferior planets as far as relates to their ſituation with reſpect to the ſun. The motion of the earth affects thoſe appearances, to ſpeak in general, only by retarding the time in which they return again to the ſame ſituation.

The earth at E, (fig. 33.) is a ſuperior planet with reſpect to Venus. A ſpectator on Venus at B, would ſee the earth E elongated from the ſun under the angle EBS, which angle of elongation would increaſe by the motion of Venus in its orbit from B to V, where it becomes a right angle EvS. From J it would be ſeen in an angle of ſtill greater elongation EJS, and from M it would be ſeen directly in oppoſition to the ſun. Paſſing from M to K, V, &c. the angle of elongation would decreaſe till the arrival of Venus at N, whence the earth would appear in conjunction with the ſun, and the angle

of elongation would vaniſh. This relative motion with reſpect to the ſun is contrary to the order of the ſigns, or from eaſt to weſt, and depends entirely on the motion of the inferior planet on which the ſpectator is ſuppoſed to be placed.

If the earth E was at a diſtance indefinitely great, the lines BE, vE, JE, &c. might be eſteemed * parallel, and conſequently the ſpectator would view it always in the ſame point of the ecliptic, its ſituation as to the ſun being varied only by the apparent motion of the ſun, which is occaſioned by the real motion of Venus. But as that is by no means the caſe, an apparent motion of the earth among the ſigns of the ecliptic will be produced. Thus, the earth viewed from N, will appear among the fixed ſtars at P; from B it will appear at R; from v at O, where it will be ſtationary ſo long as the orbit of Venus does not ſenſibly differ from its tangent; from J it will be ſeen returned back to R with a retrograde motion; from M at P; from K at T; from V at Q, where it again

* Parallel lines may be defined to be *lines that tend to a point infinitely diſtant.*

becomes ſtationary; and from A it will be again ſeen at T, its motion having become direct, &c. whence we may obſerve, that

When a ſuperior planet viewed from an inferior one appears ſtationary, the inferior planet viewed at the ſame time from the ſuperior one is alſo ſtationary, and,

When the inferior planet viewed from the ſuperior one moves apparently retrograde or contrary to the order of the ſigns, the ſuperior planet has alſo an apparently retrograde motion.

But ſince the earth has an annual motion round the ſun in its orbit, we are therefore to diſcover what part of Venus's apparent motion is produced by that means. It is plain, that if the earth were at reſt, and Venus ſeen at v, its greateſt elongation, it would again be ſeen in the ſame poſition, after performing a complete revolution in its orbit. But while Venus is performing this revolution, the earth is carried from E towards W, and ſo forth. Therefore Venus muſt paſs, between two ſimilar elongations, not only a complete revolution, but likewiſe the whole angular ſpace which the earth has performed in the ſame time. Hence its periodical time may be found. For the time between

between two ſimilar poſitions is obſerved to be 583 days. Now dividing the earth's orbit into 365 equal parts or days, the angular velocity of Venus will be expreſſed by one revolution, or 365 days added to 583 days, equal to 948; and the earth's angular velocity will be 583.

The periodical times of Venus and the Earth, will be reciprocally as their angular velocities; conſequently,

As the angular velocity of Venus - -	948
Is to the angular velocity of the Earth -	583
So is the periodical time of the Earth -	365
To the periodical time of Venus - -	$224\frac{1}{2}$

Were it not for the fixed ſtars, it would be extremely difficult, if not impoſſible to prove the annual motion of the earth. We ſhould conclude, that the planets made a complete revolution between any two ſimilar ſituations with reſpect to the ſun, becauſe the ſpaces of elongation are ſimilarly deſcribed, and are in quantity the ſame, whether the earth be in motion or not. For inſtance, if the earth be fixed at E, the ſame apparent elongations will be made by Venus with any velocity whatſoever in its orbit, but they will occur more

more frequently the greater the velocity. If a motion be given to the earth in the orbit EW, Venus will approach from v to M, which is now in motion, with a velocity equal to the difference between its angular velocity and that of the earth: or if the earth's angular velocity be greateſt, it will apparently recede from M, and deſcribe its revolutions in the contrary direction to its real motion. Now, as all the apparent motion of Venus in elongation is known by its approach or receſs from the line SE, and ſince any angular motion of SE can only change the relative velocity of Venus; and ſince a change of velocity will not alter the elongations, except as to time, it is evident, that we cannot determine whether E be at reſt or no, from the appearances of the planets which revolve about the ſun. It is then from the apparent motion of the ſun, with reſpect to the fixed ſtars, that we conclude that the earth deſcribes an orbit in about 365 days.

If the ſuperior planet E were at reſt, the retrograde motion of the inferior planet v among

among the fixed ſtars will be the ſame as its motion in elongation, viz. the angle vEV. But if E move in the ſame direction as v, but ſlower, the angle or arc deſcribed by the retrograde motion in the ecliptic will be leſs than that deſcribed between the two oppoſite elongations. The ſame is true of the retrograde motion of the ſuperior viewed from the inferior planet.

For the motion of E towards W cauſes an apparent motion of the ſun towards D. And as the retrograde motion of v referred to the arc DS is ſloweſt near the elongations, it is plain that v will not become ſtationary in the ecliptic till its apparent motion in elongation from D towards S is equal to the ſun's apparent motion in the contrary direction; that is to ſay, till ſome time after paſſing the greateſt elongation, ſuppoſe at d. After which its motion becomes retrograde till it arrives at H, equidiſtant from its greateſt elongation on the other ſide, where it again becomes ſtationary, its apparent motion being equal and contrary to that of the ſun in the ecliptic. Now, the angle LEd is leſs than the angle of retrograde motion in elongation CED. And ſince

ſince the angle lEq is equal to LEd, it is alſo leſs than CED. But thoſe angles lEq and LEd are the meaſures of the retrograde motions of the ſuperior and inferior planets, when viewed from each other. Whence the propoſition is evident.

C H A P. IV.

Of the ſuperior Planets, and of the true Form of the Planetary Orbits.

THE appearance of the earth when viewed from Venus being explained, it will be eaſy to apply that explanation to the apparent motions of the ſuperior planets. Of the two inferior planets Venus ſerved us as an inſtance; and of the three ſuperior ones we ſhall ſelect Jupiter, as being the moſt bright and conſpicuous. His motions being accounted for, ſimilar obſervations and ſimilar reaſoning will obviouſly ſolve thoſe of the other planets, whoſe particular phenomena we ſhall not therefore enlarge upon.

That Jupiter revolves in an orbit, which includes that of the earth, and which reſpects the

the ſun as its center, was ſhewn in the beginning of the laſt chapter; and his apparent motions are obſerved to be ſimilar to thoſe which it was proved the earth would have when ſeen from Venus. It remains to diſcover his periodical time and diſtance from the ſun.

Let S (fig. 35.) repreſent the ſun, E the earth, J Jupiter, the circle E e a the earth's orbit, and the circle JjA the orbit of Jupiter. Suppoſe Jupiter to be in oppoſition to the ſun. The earth revolving in its orbit will, in the ſpace of 365 days, arrive again at E, but the oppoſition will not then happen, becauſe Jupiter in the mean time has moved in his orbit towards j. The earth muſt therefore paſs through the arc Ee or $33\frac{1}{2}$ days before it overtakes him. Conſequently the angular velocity of Jupiter will be expreſſed by $33\frac{1}{2}$, and that of the earth by one whole revolution, (or 365) added to $33\frac{1}{2}$, equal to $398\frac{1}{2}$. But as the periodical times are reciprocally as the angular velocities, it will be

* As the angular velocity of Jupiter	$33\frac{1}{2}$
Is to the angular velocity of the earth	$398\frac{1}{2}$
So is the periodical time of the earth	365 days
To the periodical time of Jupiter	4340 days.

* Smaller fractions being rejected, the periodical times are not minutely exact.

2 The

The periodical time of Jupiter being thus obtained, it will be eafy to determine his * heliocentric place at any time before or after the oppofition, and the proportion of his diftance from the fun to that of the earth from the fun being known, his † geocentric place may likewife at any time be difcovered. His proportional diftance is thus found.

The figure as before. Suppofe the earth to have moved from E to C, in a given time. From the time we can readily find the quantity of the angle ESC; and in the fame time Jupiter will have moved to B, the angle JSB being alfo known from its proportion to his whole periodical revolution. Subtract the angle JSB from the angle JSC, and the remainder will be the angle BSC. By obfervation find the angle BCS, or Jupiter's elongation from the fun. In the triangle CBS, the fum of the two angles BSC and BCS being taken from 180 degrees, leaves the angle CBS. Then, by plain trigonometry,

As the fine of the angle of the earth's elongation, when viewed from Jupiter CBS

* Viewed from the fun as a center.

† Viewed from the earth as a center.

Is to the ſine of the angle of Jupiter's elongation, when viewed from the earth BCS,
So is the earth's diſtance from the ſun CS
To Jupiter's diſtance from the ſun BS.

The angle of the earth's elongation, when viewed from Jupiter, is called Jupiter's annual parallax, and is always equal to the difference between his heliocentric and geocentric place in the ecliptic, as a little conſideration will ſhew.

By ſimilar obſervations on the ſuperior planets, Mars and Saturn, it is determined that they revolve round the ſun, and that their apparent motions are attended with circumſtances of the ſame nature as thoſe of Jupiter.

Thus far we have ſpoken of the appearances of the planets, as if their revolutions were performed in circular orbits, in the center of which the ſun was ſuppoſed to be placed. But this is not the caſe. Conjunctions, oppoſitions, ſimilar elongations, or other mutual ſituations of the planets, do not return again in exactly the ſame time, and their diſtances from the ſun are found to be greater or leſs in different parts of their orbits, their

their angular velocities being always greater when the diſtance is leſs. Thus, by the increaſed diameter of the ſun during the winter half-year, we find that our diſtance is diminiſhed; and that our velocity is increaſed, appears from the apparent motion of the ſun, by which he paſſes through the winter half-circle of the ecliptic in near eight days leſs than he employs to deſcribe the ſummer-half. By a variety of obſervations of elongation or parallax, the relative or proportional diſtances of the planets from the ſun, and their velocities are found for every heliocentric poſition. Whence they are proved to revolve in elliptical orbits, in one focus of which the ſun is placed, and with ſuch velocities, that a radius drawn from the ſun to the planet, and ſuppoſed to move with it, does deſcribe equal areas in equal times.

The diſtance between the center S (fig. 35.) and one of the foci C of an elliptical orbit, is called its eccentricity. The two extreme points of the tranſverſe or longeſt diameter L and U, are called the apſides. If the focus about which the equal areas are deſcribed be at C, the nearer point L is called the lower apſis

apſis, and A is called the upper apſis, and the diameter AP is called the line of the apſides. But it is more common to ſay, that a planet is in its perihelium when at P, and in its aphelium when at A. When the earth is in its perihelium, the ſun is ſaid to be in its perigee, and when the earth is in its aphelium, the ſun is ſaid to be in its apogee.

The eccentricities of the planets are ſo ſmall, that their orbits approach nearly to circles.

If the plane of the earth's orbit were extended indefinitely every way, it would mark that circle in the heavens which is called the ecliptic, or ſun's path. If the orbit of any other planet be ſituated in this plane, it will always be ſeen in the ecliptic, whether viewed from the earth or the ſun. But if the plane of the planet's orbit be obliquely ſituated with reſpect to that of the ecliptic, it will interſect it in a line paſſing through the center of the ſun, and the planet will never be ſeen in the ecliptic but when in the points of interſection. Theſe oppoſite points of the ecliptic are called the nodes, and the line of interſection is called the line of the nodes. When a planet croſſes the ecliptic

from ſouth to north, the node is termed the aſcending node; and when it croſſes from north to the ſouthward, the node is termed the deſcending node.

The orbits of all the planets are inclined to the ecliptic in ſmall angles.

CHAP. V.

Of the Affections of the Planets.

BY ſuppoſing ourſelves in the place of one of the ancients who diſcovered the order of the planetary ſyſtem, we have diſplayed in a curſory manner ſome of the moſt obvious phenomena, and pointed out their natural conſequences. What has been ſaid is ſufficient to ſhew to thoſe who are totally unacquainted with the ſubject, that the idea of a ſyſtem of bodies revolving round the ſun is not a mere idea, but is founded on the moſt natural deduction from the celeſtial appearances. For the proceſſes by which the planets places are determined in elliptical orbits, we refer the reader to treatiſes which are written expreſsly on the ſubject, and in the

the mean time proceed to note ſeveral of thoſe affections of the heavenly bodies, as determined by the accurate obſervations of modern times.

Six planets, Mercury, Venus, the Earth, Mars, Jupiter, and Saturn, revolve about the Sun in orbits included within each other, in the order in which we have mentioned their names, Mercury being nearest the Sun. Theſe are called primary planets, beſides which, there are ten which are called ſecondary planets, Moons or Satellites. The ſecondary planets reſpect the primary planets, performing the revolutions about them, but are at the ſame time carried round the Sun in the orbit of the primary. Saturn is attended by five Moons, Jupiter by four, and the Earth by one, all which, except the laſt, are inviſible to us, by reaſon of their ſmallneſs and diſtance, unleſs teleſcopes of a conſiderable magnifying power are uſed. Without this aid, it would likewiſe be impoſſible to aſcertain the apparent diameters of any of the cœleſtial bodies, the Sun and Moon excepted. Here follow ſome of the affections of the primary planets.

Names.	Mercury.	Venus.	The Earth.	Mars.	Jupiter.	Saturn.
Greatest elongation of inferior, and parallax of superior planets.	22° 46′	46° 41′	* *	41° 00′	11° 5′	6° 00′
Proportional mean distances from the Sun. — — —	38710	72333	100000	152399	520116	953806
Periodical times. — —	d. h. m. 87 23 16	d. h. m. 224 16 $49\frac{1}{2}$	d. h. m. 365 6 $9\frac{1}{2}$	d. h. m. 686 23 $27\frac{1}{2}$	d. h. m. 4332 12 $20\frac{1}{2}$	d. h. m. 10759 6 $36\frac{1}{2}$
Times of diurnal revolutions. —	Unknown.	d. h. m. 0 23 00	d. h. m. 0 23 56	d. h. m. 1 00 40	d. h. m. 0 9 56	d. h. m. Unknown.
Daily mean motions in the ecliptic	4° 5′ 32″	1° 36′ 8″	0° 59′ 8″	0° 31′ 27″	0° 4′ 59″	0° 2′ 0″
Inclinations of orbits to the ecliptic	6° 54′	3° 24′	0° 0′	1° 52′	1° 20′	2° 30′
Eccentricities. — —	7970	517	1490	141000	25050	54700
Proportion of light. — —	700	200	100	43	$3\frac{1}{12}$	$1\frac{1}{10}$
Greatest apparent diameters geocentric. — —	0′ $11\frac{1}{2}$″	1′ 25″	Sun 32′ 38″ $\frac{1}{2}$	0′ 30″	1′ 4″	0′ 30″
Place of the aphelium. — —	♐ 13° 7′ 54″	♒ 4° 19′ 54″	♑ 8° 1′ 10″	♍ 0° 31′ 54″	♎ 9° 9′ 54″	♐ 27° 49′ 54″
Place of the ascending node. —	♉ 15° 1′ 54″	♊ 14° 25′ 54″	* * *	♉ 18° 29′ 54″	♋ 7° 19′ 54″	♋ 21° 49′ 54″
Mean distances from the sun in geographical miles. — —	31670930	59181740	81818450	124690500	425551000	780385350
Proportional diameters to that of the sun 10000. — —	36	114	90	$81\frac{1}{2}$	1738	1256
Diameters in geographical miles, that of the sun being 776970.	2825	8841	6875	6335	135079	9 566

C H A P. VI.

Of Parallaxes, and of the Tranſit of Venus.

ONE of the moſt uſual methods of meaſuring inacceſſible diſtances, is by means of two ſtations whoſe diſtance from each other is known, and the angles formed at each ſtation between lines, ſuppoſed to be drawn from the diſtant object to them, and the line which joins the ſtations to each other. Thus the diſtance between A and B (fig. 36.) being known, as likewiſe the angles CAB and CBA, the diſtance AC or BC may be readily found by plane trigonometry.

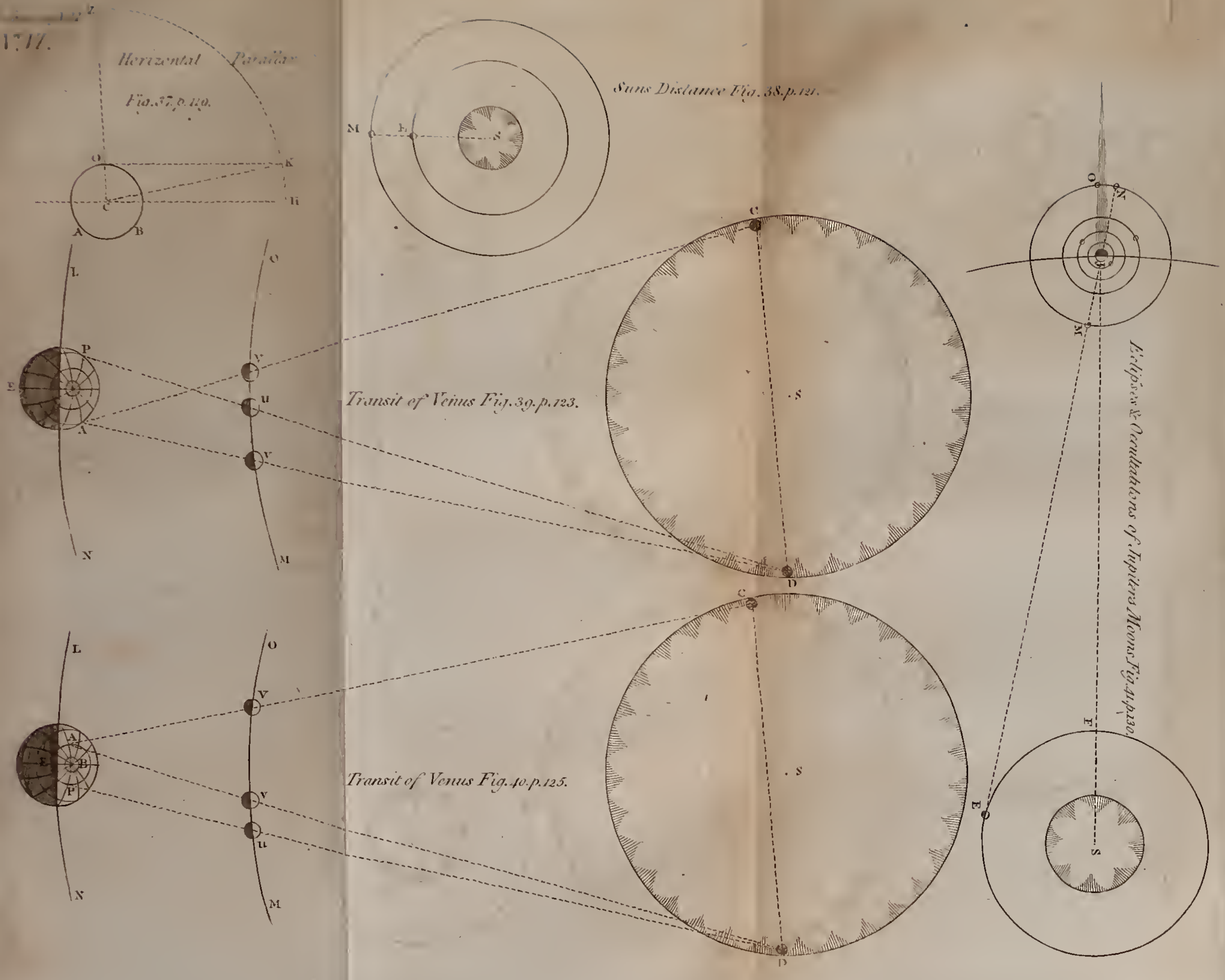
Suppoſe the object C when viewed from B, (fig. 36.) to coincide with another object S, which is at a diſtance indefinitely great; Then the object C will not appear to coincide with S, when viewed from A. For S, on account of its great diſtance, will be ſeen in the line AS, parallel to BS; and C will be ſeen in the line AC, the angle SAC being the difference between the apparent places

from A and B. This angle, becauſe of the parallels AS and BS, will be always equal to the angle ACB, and is by aſtronomers called the parallax, being diſtinguiſhed by ſome appellation relative to the nature of the line AB: for inſtance, it is the annual parallax, when AB is the radius of the annual orbit; the horizontal parallax, when AB is the diſtance between the rational and ſenſible horizon, &c.

It is almoſt unneceſſary to obſerve, that the longer the line AB is in proportion to the diſtance of C, the greater the angle ACB, and that in general, the greater the angle the leſs is the diſtance affected by any ſmall error. It is therefore requiſite that the baſe AB be as large as poſſible or convenient.

The diſtances of the planets were found by trigonometry, the diſtance of the earth from the ſun being aſſumed as a baſe. But as that baſe cannot actually be meaſured, the ſaid diſtances are only proportional or relative, it being ſuppoſed to be divided into 100000 equal parts; but whether thoſe parts are miles, leagues, or any other denomination of length was not determined. The real diſtances muſt

N.° 17.



Horizontal Parallax Fig.37.p.119.

Suns Distance Fig.38.p.121.

Transit of Venus Fig.39.p.123.

Transit of Venus Fig.40.p.125.

Eclipses & Occultations of Jupiters Moons Fig.41.p.130.

muſt be diſcovered by a parallax whoſe baſe is known.

The diameter of the earth is the longeſt right line, whoſe length we can obtain by admeaſurement, and is in general the baſe uſed for determining the diſtances of cœleſtial objects by their parallax, which parallax is found as follows.

Let ABO, (fig. 37.) repreſent the earth, C its center, and Z the zenith or point in the heavens ſituated perpendicularly over the point O at its ſurface. Then CH will be the rational horizon, and OK the ſenſible horizon. Suppoſe a ſpectator at C views a celeſtial object at Z, the revolution of the earth will cauſe it to move apparently through the quadrant ZH in ſix hours, at the end of which time he will ſee it in the horizon at H. But to a ſpectator at O it will appear in the horizon when at K, paſſing through the quadrant or right angle ZOK, in a time as much leſs than ſix hours as the arc ZK is leſs than ZH, or 90 degrees. Hence the time of an object's paſſing between the zenith and ſenſible horizon being known, the angle OKC, or horizontal

parallax, may be found. For as ſix hours is to 90 degrees, ſo is the time obſerved to the arc ZK, which being taken from 90 degrees, leaves the arc KH or angle KCH, which is equal to OKC, or the horizontal parallax.

The horizontal parallax being diſcovered, the diſtance of the object follows by this analogy; in the triangle OKC.

As the horizontal parallax, ſine		OKC
Is to the earth's ſemidiameter	-	OC
So is radius - -	ſine	90°
To the diſtance - -	-	CK

The fixed ſtars have no parallax, either horizontal or even annual, whence it follows, that their diſtances are beyond all compariſon greater than that of the earth from the ſun.

The ſun's parallax is ſo exceeding ſmall, that the beſt inſtruments in the hands of the moſt ſkilful obſervers, have ſcarcely effected more than to ſhew that it has one. To remedy this, the horizontal parallaxes of the nearer planets have been attempted, particularly of Mars, when in oppoſition to the Sun, he being then as near again to the Earth as the Sun is, and has therefore a parallax twice as great. But as this parallax is not found

to

to exceed half a minute of a degree, the unavoidable uncertainty of obſervation and other cauſes render it not ſufficiently exact to determine the diſtance within a 30th part of the whole. It is eaſy to comprehend how the Sun's diſtance may be found when the diſtance of Mars, from the earth, in oppoſition is known. Thus, if S, (fig. 38.) be the Sun, E the Earth, and M Mars in oppoſition, then EM will be the diſtance of Mars from the Earth, and alſo the difference between MS and ES, or the reſpective diſtances of Mars and the Earth from the Sun. The proportional diſtances are known. Therefore,

As the difference between the proportional diſtances of Mars and the Earth from the Sun,

Is to the proportional diſtance of the Earth from the Sun;

So is the diſtance between the Earth and Mars in oppoſition, or the difference between their real diſtances from the Sun,

To the Earth's real diſtance from the Sun.

Several other methods were deviſed by the ancients for diſcovering the Sun's parallax, which, though they ſhew the ſagacity and penetration

penetration of their inventors, are lefs fuffici-ent for the purpofe than the foregoing. We fhall therefore omit mentioning them, and give a fhort explanation of that for which we are indebted to the great Dr. Halley, by which the folar diftance is determined with-in one five-hundredth part of the whole.

The planet Venus, as has been fhewn, paffes the Sun twice in revolving from any pofition of elongation to the fame pofition again. At thofe times fhe is faid to be in conjunction with the Sun.

When Venus is fituate in a line between the Sun and the Earth, fhe is faid to be in her inferior conjunction; and when fhe is in the oppofite part of her orbit, the Sun being in a line between her and the Earth, fhe is faid to be in her fuperior conjunction. If the orbits of the Earth and Venus lay in the fame plane, it is evident that Venus would pafs behind the Sun with a direct motion every fuperior conjunction, and would pafs over his * difc, or before him, with a retro-grade motion every inferior conjunction. But

* Surface.

as

as Venus's orbit is inclined to the ecliptic in an angle of about 3 ½ degrees, ſhe will in general paſs to the northward or ſouthward of the ſun, and will only be viſible on his diſc when the inferior conjunction falls out at or near one of the nodes. This happens but once (or ſometimes twice at an interval of about 8 years) in more than 120 years.

To ſhew how this tranſit is applied to the purpoſe of finding the Sun's diſtance, we ſhall paſs over thoſe elements which enter into the computation previous or ſubſequent to actual obſervation, and ſhall only explain the general principles on which the method is founded.

Let S (fig. 39.) repreſent the Sun, E the earth, V, u, v, the planet Venus in different poſitions, the arc L N a part of the Earth's orbit, and the arc O M a part of Venus's orbit. Then, becauſe the angular velocities of Venus and the Earth are known, as alſo their proportional diſtances, it will be eaſy to compute the time Venus will be paſſing through the arc V v, which when viewed from the Earth is equal to the known diameter (or chord) of the Sun C D; the heliocentric

tric value or length of the arc V v may likewiſe be readily found. Suppoſe then an obſerver at A on the Earth's ſurface to view the planet Venus at V, it will appear juſt entered within the Sun's diſc at C, and paſſing in the arc V v, will appear to deſcribe the line C D, arriving at D at the end of the computed time. But during this time the obſerver will, by the Earth's diurnal revolution, be carried from A towards P; and arriving at P at the ſame inſtant that Venus arrives at U, will behold the tranſit juſt finiſhing at D: conſequently it will be of a duration as much ſhorter than the computed time, as the heliocentric arc V u is ſhorter than V v. The arc V v is known by computation, therefore (ſince Venus's motion may in very ſmall arcs be reckoned uniform)

As the computed time
Is to the computed arc V v,
So is the obſerved time
To the arc - - V u;

which being taken from V v, leaves the arc u v, which ſubtends the angle uDv. This laſt angle is the parallax of the baſe A P; and the baſe AP is found by the analogy

As

As one day or 24 hours
Is to the circumference of the earth (or parallel of latitude)
So is the obſerved time
To the arc A P, whoſe chord is the baſe.

But becauſe the minuteſt errors in a buſineſs of this nature are of very great conſequence, and becauſe the length of the arc V v can ſcarcely be obtained by calculation to that extreme degree of exactneſs, which is requiſite, it is adviſable to take another obſervation on the oppoſite * meridian of the Earth, where the obſerver being carried in a direction apparently contrary to the former, the errors may counteract each other.

Let the repreſentations be as in the laſt figure. If the Sun have declination at the time of the tranſit, B (fig. 40.) will repreſent the pole towards which the Sun declines. The obſerver at A, if at reſt, would behold the tranſit during the time Venus paſſes from V to v, but being by the earth's diurnal revolution carried from A through the arc AEP to P, and arriving at P at the inſtant in

* Vide ch. 12. of this ſection.

which

which Venus arrives at u, he will then perceive the tranſit juſt finiſhing at D; conſequently its duration will be as much longer than the computed time as the heliocentric arc V u is longer than V v. V u being found by the before-mentioned analogy, the difference between V u and V v is v u, or the parallax of A P, as before.

Now, in theſe two caſes, a ſimilar error will have a contrary effect in the firſt to that which it has in the latter. For if by any error, the computed arc V v (fig. 39.) be taken greater than juſt, the arc u v, and conſequently the parallax will come out too great. But in the latter obſervation, if the computed arc V v (fig. 40.) be taken greater than juſt, the arc v u, and conſequently the parallax will come out too little. Therefore the mean between two ſuch obſervations will be much more to be depended on than either ſingly.

By obſervations on the tranſits of Venus over the Sun in the years 1761 and 1769, the Sun's mean parallax was found to be $8\frac{3}{5}$ ſeconds, and hence the Sun's diſtance is deduced

duced to be very near 11900 diameters of the earth, or 81818450 * geographical miles.

The laſt three articles in Chap. V. concerning the affections of the planets are deduced from this diſtance; for,

As the proportional diſtance of the earth
Is to its real diſtance,
So is the proportional diſtance of any other planet
To its real diſtance.

CHAP. VII.

Of the Secondary Planets.

THE ſecondary planets, as was before obſerved, are ten in number, five of which deſcribe orbits about the planet Saturn, four about Jupiter, and one accompanies the Earth. The ſecondaries of Saturn and Jupiter are obſerved by the teleſcope, and by their motions in elongation to the eaſtward or weſtward of their primaries is obtained the knowledge of their diſtances and periodical times,

* A geographical mile is $\frac{1}{60}$ part of a degree of the earth. 69 $\frac{1}{2}$ Engliſh miles make a degree.

in

in the manner which has been already instanced in the planet Venus. Saturn is likewise attended by a phenomenon, which to us appears to be a large broad ring, of no visible thickness. Its breadth is equal to its distance from the body of the planet, and its diameter is to that of Saturn as 9 to 4. The most probable conjecture is, that it consists of a vast number of satellites, which revolve in, and enlighten that region.

Of Saturn's five moons, the periodical times $1^{d}\ 21^{h}\ 19^{m}$—$2^{d}\ 17^{h}\ 41^{m}$—$4^{d}\ 13^{h}\ 47^{m}$—$15^{d}\ 22^{h}\ 41^{m}$—$79^{d}\ 22^{h}\ 41^{m}$.—Distances in semidiameters of the ring, $1\frac{95}{100}$—$2\frac{5}{10}$—$3\frac{52}{100}$—$8\frac{9}{100}$—$23\frac{71}{100}$. — Of Jupiter's four moons, the periodical times, $1^{d}\ 18^{h}\ 27^{m}\ 34^{s}$—$3^{d}\ 13^{h}\ 13^{m}\ 42^{s}$—$7^{d}\ 3^{h}\ 42^{m}\ 36^{s}$—$16^{d}\ 16^{h}\ 32^{m}\ 9^{s}$—Distances in semidiameters of Jupiter $5\frac{667}{1000}$—$9\frac{17}{1000}$—$14\frac{384}{1000}$—$25\frac{299}{1000}$.

All the planets, both primary and secondary, receive their light from the Sun. This is evident, because that face only is illuminated which is turned towards him, as may be more particularly seen in our Moon, a greater or less part of which is visible, according to the position in which we lie for viewing the

illuminated face. The ſame varieties are ſeen in the planets Mars and Venus, not to mention the tranſits of Venus and Mercury over the Sun, at which time they appear as black unenlightened ſpots. The phaſes of Jupiter and Saturn are always round and full, becauſe the Earth is ſo near the Sun in reſpect to their diſtances, that their dark ſide can never be ſenſibly turned towards us; yet, that they are opake, is evident from the diſappearing of Jupiter's moons when they enter into his ſhadow: and though by reaſon of their vaſt diſtance the like obſcurations of the ſatellites of Saturn cannot be obſerved, yet we can plainly ſee that the ring caſts a ſhadow on his body: whence we may be certain of the opacity of both: for if the ring were not opake it could caſt no ſhadow, and if Saturn ſhone by any native light of his own, the interception of the Sun's light would cauſe no defect or ſhadow on his body. It is unneceſſary to obſerve, that the earth and its moon are illuminated only on that part or ſide on which the Sun ſhines.

When one planet intercepts any part of the Sun's light from another, the planet from

which the light is intercepted is ſaid to be eclipſed, if it be a ſecondary. But if they are both primaries, the inferior planet is ſaid to make a tranſit. When the moon intercepts the Sun's light from the Earth, it is uſual to ſay the Sun is eclipſed, though, properly ſpeaking, it is the Earth that is eclipſed.

The ſatellites of Jupiter, when viewed from the Earth, do diſappear in three different manners: thus, let S (fig. 41.) repreſent the Sun, E the Earth in its orbit, J Jupiter and his moons: then the outermoſt ſatellite, for inſtance, will diſappear on the enlightened face of Jupiter when at its inferior conjunction M. It will alſo diſappear at its ſuperior conjunction N, being hid behind the body of the planet. And laſtly, it will diſappear when at O, being eclipſed in paſſing through the ſhadow of Jupiter.

From theſe conſiderations is obtained a good method of finding the parallax of the Earth's annual orbit. For which purpoſe the inſtant of the ſatellite's firſt diſappearance behind the body of Jupiter muſt be carefully obſerved, as likewiſe the inſtant of its re-appearance: the middle inſtant will be that of the

ſuperior

ſuperior conjunction at N. In like manner, find the middle-inſtant of the eclipſe at O, and the time the ſatellite employs in paſſing through the arc N O will be known, and conſequently the angle NJO. For,

As the periodical time of the ſatellite
Is to the time of paſſing the arc NO,
So is the whole orbit or 360 degrees
To the angle NJO.

But the angle NJO is equal to the angle EJS, or the annual parallax.

By the obſervations of theſe eclipſes, the diſcovery of the longitude on ſhore is eaſily obtained, but the violent motion of ſhips at ſea prevents the uſe of teleſcopes on board. From theſe obſervations it alſo appears, that light is not propagated from luminous bodies in an inſtant, but paſſes through a given ſpace with an aſſignable velocity. This velocity is inexpreſſibly great, for it paſſes through the whole diſtance between the Sun and the Earth in about eight minutes; that is to ſay, at the rate of one hundred and ſeventy thouſand miles in a ſecond of time: for the periodical times of the ſatellites being known, it is eaſy to determine the preciſe time of any of their

 eclipſes.

eclipſes. But it is found neceſſary to make an allowance for the poſition of the Earth with reſpect to Jupiter, ſince the eclipſes happen ſooner when the Earth is at F, (fig 41.) in her orbit, than when at a greater diſtance, ſuppoſe at E; and as it is abſurd to ſuppoſe, that the motion of the Earth ſhould influence the motions of bodies ſo vaſtly remote, it is an opinion univerſally received, that the eclipſes do happen later when the Earth is at E than when at F, becauſe the light muſt in the latter caſe paſs through a ſpace as much greater as the line JE exceeds JF.

C H A P. VIII.

Of the Moon.

THAT the Moon revolves round the Earth is proved from her apparent diameter, which continues at all times, and in all poſitions, nearly of the ſame magnitude, whence we infer, that her diſtance from the Earth is nearly at all times the ſame. Her horizontal

tal parallax, which at a medium is about 57′, ſhews that ſhe is very much nearer to us than the reſt of the celeſtial bodies, and by conſequence much ſmaller.

The moſt remarkable appearance that ſtrikes the obſerver is the continual change of figure to which the Moon is ſubject. Sometimes ſhe appears perfectly full or circular, at other times half illuminated, and at other times more or leſs than half; changing through a very great variety of figures. Theſe changes, which are always the ſame at the ſame elongation from the Sun, are a proof that ſhe receives her light from him; that ſide of the Moon only being enlightened which faces the Sun; of which enlightened part a greater or leſs quantity is viſible to us, according to our poſition. This cannot be better illuſtrated than by an ivory ball, which being held in the Sun in various poſitions, will preſent a greater or leſs part of its illuminated ſide to the view of the obſerver. If it be held nearly oppoſite, ſo that the eye of the obſerver be almoſt between it and the Sun, the whole enlightened ſide will be ſeen. But if it be moved in a circular orbit towards the

Sun, the viſible enlightened part will gradually decreaſe, and at laſt diſappear when the ball is held directly towards the Sun. Or, to apply the experiment more immediately to our preſent purpoſe; if the ball at any time, when the Sun and Moon are both viſible, be held directly between the eye of the obſerver and the Moon, that part of the ball on which the Sun ſhines will appear exactly of the ſame figure as the Moon itſelf.

The Moon's path or orbit is inclined to the plane of the ecliptic, in an angle of about five degrees and a quarter. Her periodical revolution is performed in twenty-ſeven days and ſeven hours; but, becauſe during that time the Sun, by his apparent motion, advances conſiderably in the ecliptic, a ſpace of about two days and a quarter is required by the Moon to overtake him. When the Moon is in a line between the Earth and the Sun, it is called the New Moon; and when the Earth is in a line between the Moon and the Sun, it is called the Full Moon. The time between two ſucceeding full moons is called the ſynodical revolution, and exceeds the periodical revolution, for the reaſon juſt given,

given, it being performed in twenty-nine days and a half. If the new or full Moon happen near the node, an eclipſe takes place; at the new Moon, the Moon being interpoſed between the Sun and Earth, occaſions an eclipſe of the Sun; at the full Moon, the Moon entering into the ſhadow of the Earth, is deprived of the Sun's light, the Earth being interpoſed between it and the Sun: this is a lunar eclipſe, or eclipſe of the Moon. At other times, that is, when the new or full Moon happens at a diſtance from the node, the Moon paſſes too far to the northward or ſouthward of the ecliptic, either to intercept the Sun's light from the Earth, or to enter the Earth's ſhadow, and conſequently no eclipſe happens.

From obſervations of the Moon's angular velocity, parallax and apparent diameter, it is found, that ſhe revolves round the Earth in an elliptical orbit, in the focus of which the Earth is placed; and that her velocity is ſuch, that a radius joining her center with that of the Earth does (very nearly) deſcribe equal areas in equal times.

The line of the apſides, or principal diameter of the Moon's orbit, is not fixed or ſtationary, but revolves with an irregular motion from weſt to eaſt; completing one revolution in almoſt nine years.

The line of the nodes is likewiſe ſubject to an irregular motion from eaſt to weſt, which is completed in almoſt nineteen years.

The variation of the Moon's motion in any part of her orbit is the difference between her real motion and that which ſhe would have had, provided ſhe deſcribed equal areas in equal times. This is governed chiefly by her elongation from the Sun. During the firſt quarter of her motion ſhe loſes ſomething of her ſwiftneſs; in her ſecond quarter, from the quadrature to the oppoſition or full Moon, ſhe increaſes in velocity; in her third quarter, from the oppoſition to the laſt quadrature, ſhe again loſes part of her motion; and from that quadrature to the conjunction, her velocity is again increaſed. The quantity of angular motion loſt exceeds the quantity gained: Therefore the whole periodical revolution is performed in a longer

longer time than would be required if the Moon was ſubject to no ſuch variation, but deſcribed equal areas in equal times.

This variation, and conſequently the retardation of the periodical time is greater when the Earth is in the perihelium, and leſs when the Earth is in the aphelium: whence it is, that all her revolutions are not equal; they being performed in leſs time in the latter ſituation than in the former.

On all theſe ſeveral accounts, the determination of the Moon's place in the heavens for a given inſtant of time has ever been a problem of great difficulty, which till of late years has not been ſolved to any conſiderable degree of exactneſs. Within the laſt twenty years the commiſſioners appointed by the Engliſh government for the diſcovery of the longitude have particularly attended to this branch of aſtronomy, and by publiſhing almanacs in which the Moon's elongation from the Sun, and from certain fixed ſtars, is aſcertained for every three hours, have enabled navigators to determine the ſituation of ſhips at ſea in general within thirty miles of the truth. This

is

is an advantage of ſingular uſe in long voyages, and is at preſent much uſed in the royal navy, and Eaſt India Company's ſhips.

CHAP. IX.

Of Comets; and of the Proportion of Light and Heat on the Planets.

BESIDES the ſix primary planets, and their moons or attendants, there is obſerved a peculiar kind of erratic bodies, which are called Comets. Theſe appear occaſionally in every part of the heavens, and move in very long ellipſes, in the lower focus of which is the Sun. By obſervations of parallax it is found, that at their firſt appearance they are nearer to us than Jupiter: whence it is concluded, that they are much leſs than him; for if they were as large as Saturn they would be ſeen as far off.

The orbits of the comets are inclined to the plane of the ecliptic in very large angles; therefore, except when at or near their nodes, they are in general too far north or ſouth of the

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the planetary orbits to endanger the ſyſtem by any ſhock or occurſion againſt the planets.

When a comet arrives within a certain diſtance of the Sun, it emits a fume or vapour, which is called its tail. This ſhews that they are conſiderably more rare and volatile than the Earth; for the tail begins to appear while they are yet in a higher and conſequently colder region than Mars. The tail is always directed to that part of the heavens which is directly or nearly oppoſite to the Sun; and is greater after the comet has paſt its perihelium than during its approach towards it, being greateſt of all at the time when it has juſt paſt the perihelium.

That part of a comet's orbit which comes under our obſervation is ſo ſmall in proportion to the whole, that in moſt it does not ſenſibly differ from a parabola: therefore the dimenſions of their orbits and periodical times cannot be thence determined with any degree of preciſion. But from the re-appearance of comets after long intervals of time in the ſame region of the heavens, and moving in the ſame curve, there is the higheſt reaſon to conclude that they do revolve about the Sun

Sun in very long or eccentric ellipſes; being governed by the ſame law of deſcribing equal areas in equal times, which we find to obtain in the inferior part of their orbits. The comet which appeared in the year 1661 was ſeen before in the ſame orbit, and under the ſame circumſtances (fig. 42.) in the year 1532; which ſhews its period to be 129 years: if it re-appears in the year 1790, its identity will be yet further confirmed. In like manner, the comet which appeared in the year 1531, 1607, 1682, and 1759, is determined to revolve in a period of about ſeventy-ſix years. And that very remarkable comet which was obſerved in the year 1680, is ſhewn to be the ſame with that which appeared in the year 1106; its period being 575 years. The diſtace of this comet from the Sun, when in its perihelium, was to the diſtance of the Earth from the ſame, in round numbers, as 6 to 1000: its heat therefore at that time was to the heat of the ſummer's ſun with us as 1000000 to 36, or as 28000 to 1. But the heat of boiling water is about three times the heat which dry earth acquires from the ſummer's ſun; and the heat of red-hot iron may

may be about 3 or 4 times as great as that of boiling water. And therefore, the heat which the Comet acquired, ſuppoſing it to be compoſed of dry earth, was about 2000 times greater than that of red-hot iron. By ſo fierce a heat, there is no doubt but vapours, exhalations, and every volatile matter muſt have been immediately conſumed and diſſipated.

Comets when viewed by means of the teleſcope, have the appearance of maſſes of ignited matter. In ſome the diſc is well defined, and of an uniform colour, in others rough, broken and duſky. But theſe characters are not uniform in the ſame comet: as they approach the Sun they grow more ignited and luminous, and on their receſs they ſeem to cool, and ſometimes crack into pieces, ſome of which loſe their brightneſs ſooner than others. In all ſituations a comet appears, even to the naked eye, very different from any celeſtial body. Neither the ſparkling vivacity of the fixed ſtars, nor the ſteady ſerene light of the planets are to be obſerved, but a peculiarity of appearance that would render

them very distinguishable, even if their tails were wanting.

The number of the comets does much exceed that of the planets. Within the four last centuries, about 25 have been observed, whose orbits are for the most part sufficiently ascertained to enable future astronomers to know them again. But we have reason to believe, that many others have appeared during that time without being noticed.

That laudable curiosity which prompts the human mind to search into the works of nature, is not satisfied with the bare relation of facts. Convinced, almost intuitively, of the wisdom of the SUPREME INTELLIGENCE, we are continually drawing inferences which lead to the final causes of things. For example, we are not satisfied in knowing that trees do vegetate: the mere knowledge is of little importance without an attention to the final cause. For what purpose do they vegetate is naturally demanded?—To promote the evaporation of fluids from the lower part of the Earth's surface to which the rain may soak, but where the effect of the Sun is scarce

perceived

perceived — to afford an asylum to the feathered race, and a shade to terrestrial animals——to supply food for a variety of creatures, &c. &c. This mode of enquiry is adopted without any suspicion that it may be possible for things to exist without any final purpose. So far are we from admitting any such doubt, that, when the final cause of any particular phenomenon is not obvious, we never fail to conclude that it is *undiscovered*, and not that no such cause exists; for the existence of a final cause is always taken for granted. That such proceeding is justifiable might be easily proved, but since it never was doubted but by a few who had deceived themselves by * metaphysical reasoning on

* The objects of metaphysical enquiry being very abstracted, and, in many instances, not determinable for want of first principles, it has seldom happened that writers have kept their imaginations subservient to their reason. False axioms and similies are used instead of logical argumentation, and error has been admitted on all sides. It is much to be regretted, that this most sublime science should still remain in the infant state in which it was left by the great Locke.

false

false principles, it is unnecessary in this place to attend to it.

On this ground, an enquiry into the final causes of the planetary bodies offers itself to us. The Earth is shewn to be a planet in circumstances very similar to the other five: we know its final cause—to support a number of inhabitants. And by analogy, we may easily conclude, that the others are also habitable worlds; though from their different proportions of heat it is credible, that beings of our make and temperature could not live upon them. Yet it would be rather premature to affirm even that; for the warmest climate on the planet Mars is not colder than many parts of Norway, or Lapland are in the spring or autumn. Jupiter and Saturn, it must be granted, are colder than any of the inhabited parts of our globe. The greatest heat on the planet Venus, exceeds the heat in the island of St. Thomas on the coast of Guinea, or Sumatra, in the East Indies, about as much as the heat in those places exceeds that of the Orkney islands, or that of the city of Stockholm in Sweden: therefore, at 60 degrees north latitude on that planet,

sup-

ſuppoſing its axis perpendicular to the plane of its orbit, the heat would not exceed the greateſt heat of the Earth, and of courſe, vegetation like ours might be there carried on, and animals of the ſpecies on Earth might ſubſiſt. If Mercury's axis be ſuppoſed to have a like poſition, a circle round each pole of about 20 degrees diameter would enjoy the ſame temperature as the warmer regions of the Earth, though in his hotteſt climate water would continually boil, and moſt inflammable ſubſtances would be parched up, deſtroyed, or diſſipated into vapor. But it is not at all neceſſary that the planets ſhould be peopled with animals like thoſe on the Earth, the Creator has doubtleſs adapted the inhabitants of each to their ſituation.

From what has been juſt ſaid, a better idea may be formed of the proportions of heat on the planets than can be conveyed by numbers. It will not be from the purpoſe to compare the light of the ſuperior planets with that of our day, from whence it will appear, that though ſo remote from the Sun, they are by no means in a ſtate of darkneſs. This might be inſtanced by ſeveral different methods,

as by the Sun's light admitted into a dark chamber, and received on paper with different degrees of obliquity; by a greater or leſs number of candles brought into a room for the purpoſe of illuminating it with different proportions of light; or by various optical methods: but we ſhall not enlarge upon them. It will be ſufficient for the illuſtration of the ſubject to compare their different proportions of light with that of a moonſhine night, at the time of the full.

When the moon is viſible in the day time, its light is ſo nearly equal to that of the lighter thin clouds, that it is with difficulty diſtinguiſhed amongſt them. Its light continues the ſame in the night; but the abſence of the Sun, ſuffering the aperture or pupil of the eye to dilate itſelf, renders it more conſpicuous. Conſequently, if every part of the ſky were equally luminous with the Moon's diſc, the light ariſing from thence would be the ſame as if, in the day time, it were covered with the thin clouds above-mentioned. Therefore, this day-light is in proportion to that of the Moon, as the whole ſurface of the ſky or viſible hemiſphere is to the ſurface

of

of the Moon; that is to say, nearly as 90,000 to 1. The light of Saturn is to that of the Earth as 1 $\frac{1}{10}$ to 100, and of course equal to that of 990 full Moons: Jupiter's day will equal the light of 2775 Moons, and that of Mars will require 38,700, a number so great, that they would almost touch one another. It is even probable, that the Comets, in the most distant parts of their orbits, enjoy a degree of light much exceeding moonshine.

If the Comets are habitable, it is in a manner of which we can form no conception. There are many other uses for which it is probable they may have been formed: the fluid vapor or steam, of which their tails are composed, may be destined to recruit the waste of fluid which happens on the planetary bodies: for there is great reason to suspect, that in vegetation and other processes of nature, water is transmuted into earth. Or they may serve to recruit the waste of matter which the Sun must suffer by so constant an emission of the particles of light. After a great number of revolutions,

the reſiſtance of the Sun's atmoſphere, and a concurrence of circumſtances may occaſion them to approach the Sun, and at length fall into it, and become a part of its body.

CHAP. X.

Of the Teleſcopic Appearance of the Moon.

HYPOTHESES or conjectures are only allowable in natural philoſophy, when for want of experiment or obſervation, a leſs fallible mode of proceeding cannot be adopted. They are of uſe chiefly to point out the ſeries of enquiries neceſſary to enable the philoſopher to confirm or reject them; till thoſe enquiries are made, care muſt be had not to admit them for more than their real value. The very plauſible hypotheſes of the philoſophers who preceded the immortal Newton, were received for a time, but not being founded on a conſtant recurrence to phenomena, they are now no longer remembered, but as proofs, that the greateſt human underſtanding is unequal to the taſk of de-

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The Telescopic Appearance of the Moon.

ducing the appearances of nature by arguments *à priori* *.

The obſervations which might confirm the hypotheſis of planetary worlds ſeem to be placed beyond our power. We can ſcarce hope to make optical inſtruments ſufficiently perfect to render their inhabitants viſible to us. The groſs air with which we are ſurrounded, is a great impediment to the uſe of thoſe we already poſſeſs, and limits their perfection to a certain degree, beyond which we

* Arguments *à priori* are deductions from the cauſe to the effect; Arguments *à poſteriori* are from the effect to the cauſe. Theſe are alſo diſtinguiſhed by the names Syntheſis and Analyſis. If knowledge be obtained from without, as doubtleſs it is, it muſt be obtained by the latter method; for we perceive only effects from which we infer their cauſes. Contrary to this is the method of Des Cartes *ex ipſius Dei Cognitione, ſcientiam perfectiſſimam, quæ eſt effectuum per cauſas, acquirere.* Prin. lib. II. But when we have obtained the cauſes of things by Analyſis, the Synthetical method is very uſeful for pointing out their effects: as for example, when we have aſſured ourſelves that the cauſe or principle which we call gravity does exiſt, we may ſynthetically diſcover its effects on projectiles, &c. thrown in all the poſſible varieties of force and direction, without having recourſe to that infinity of experiments which the analytical proof would require.

cannot paſs. All, therefore, that we can do, is to examine if the planets are accommodated with thoſe things which we are uſed to conſider as neceſſary to animal exiſtence. Lands, ſeas, clouds, vapours, and an atmoſphere or body of air, are objects which we may expect to find on the face of a habitable world: what has been done in this reſpect, it is our preſent buſineſs to relate.

The Moon being ſo very near to us, and likewiſe in the ſame temperature as to light and heat, offers itſelf as the fitteſt body for examination. We diſcern a variety of ſpots with the naked eye, which the imagination naturally ſuppoſes to be ſeas, continents, and the like, but on a more accurate inſpection, with the aſſiſtance of the teleſcope, we perceive that many of thoſe appearances are occaſioned by vaſt obſcure pits or cavities, and elevations or mountains. The heights of theſe mountains may eaſily be found; for by the horizontal parallax we know the Moon's mean diſtance from the Earth is about 60 ſemidiameters of the Earth, and her mean apparent diameter is 32′ 12″, whence by

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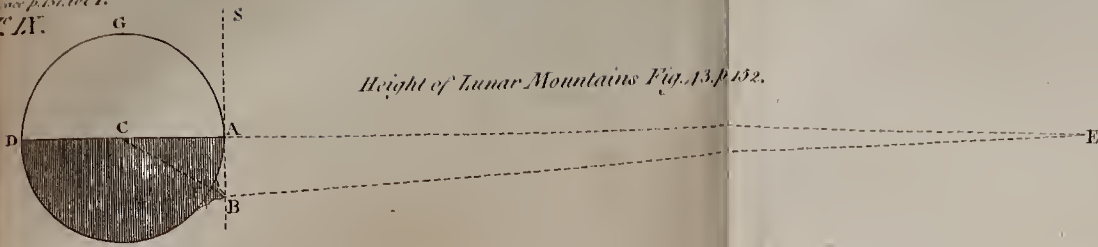
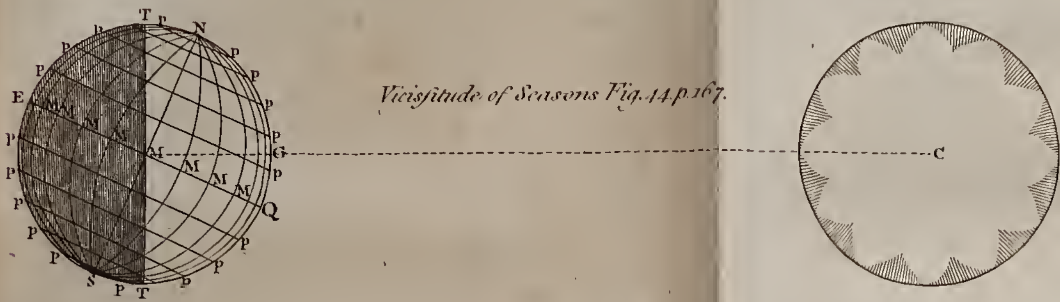
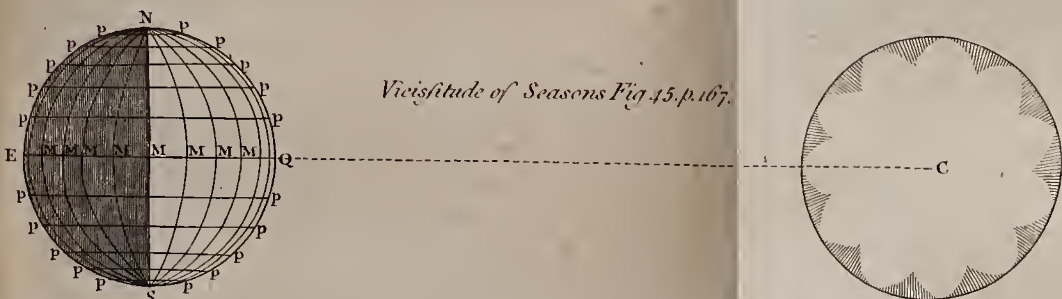


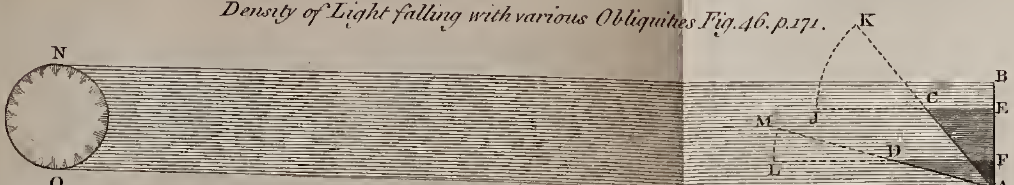
Height of Lunar Mountains Fig. 43. p. 152.



Vicissitude of Seasons Fig. 44. p. 167.



Vicissitude of Seasons Fig. 45. p. 167.



Density of Light falling with various Obliquities Fig. 46. p. 171.

by plane trigonometry, her real diameter is to that of the earth, as 100 to 365: Therefore, if we find the proportion the height of a lunar mountain bears to the Moon's diameter, we can readily find the quantity of that height in miles or other terreſtrial dimenſions.

Theſe mountains and cavities are known to be ſuch from their ſhadows. In the firſt and ſecond quarters, when the Sun ſhines obliquely on the face of the Moon, the elevated parts caſt a triangular ſhadow in the direction from the Sun; and, on the contrary, the cavities are dark on the ſide next the Sun, and illuminated on the oppoſite ſide. Theſe ſhadows ſhorten as the Sun becomes more directly oppoſed to the anterior face of the Moon, and at length diſappear at the time of the full. During the third and laſt quarters, the ſhadows appear again, but all fall towards the contrary ſide of the Moon, though ſtill with the ſame diſtinction; namely, that the mountains are dark and ſhady on the ſide furtheſt from the Sun, and the pits are dark on the ſide next the Sun. This appears likewiſe by contemplating the inner illuminated edge of the Moon. If the

Moon were an uniformly plain ſphere, this edge would be a regular curve, but if it be compoſed of hills and cavities, it is evident that the higher parts muſt be enlightened ſooner, and the cavities later than the reſt of the ſurface. This is accordingly the caſe, and affords a method of obtaining the heights of the mountains.

To render the explanation eaſier, we ſhall ſuppoſe the Moon to be in her quadrature, and the mountain to be ſituate at an equal diſtance from her poles, that is, at her equator.

Let the circle ABDG, (fig. 43.) repreſent the Moon, whoſe center is C; and E the Earth. Then a ſpectator at E will ſee the Moon enlightened in the half AGD, and the line EC will paſs through A, or the inner enlightened edge. The ray of light SAB touching the Moon at A, will croſs the line EC at right angles, and illuminate the top of the mountain B. The angle AEB is found by obſervation, then, in the triangle AEB.

As radius
Is to the Moon's diſtance - BE,
So is the ſine of the obſerved angle AEB,
To the ſide or line - - AB.

Then

Then in the right angled triangle CAB, the ſides CA and AB being known, the ſide CB is found from the well known property (47. e. 1.) that is to ſay, the ſquare of the Moon's ſemidiameter CA being added to the ſquare of the line AB, the ſquare root of the ſum is the ſide CB. And if the ſemidiameter of the Moon CF be taken from the line CB, the remainder is FB, or the height of the mountain.

From obſervations of this kind, it appears that the lunar mountains are much higher in proportion than any we have upon the Earth.

That the Moon is ſurrounded by an atmoſphere or body of air, is rendered probable by many obſervations of ſolar eclipſes, in which the limb or edge of the Sun was obſerved to tremble juſt before the beginning. The planets likewiſe are obſerved to change their figure from round to oval juſt before the beginning of an occultation behind the Moon; which can be attributed to no other cauſe, than that their light is refracted, being ſeen through the Moon's atmoſphere. Many aſtronomers are of opinion, that the Moon has no at-

moſphere,

moſphere, becauſe we ſee no clouds, and becauſe the fixed ſtars diſappear at once at the time of an occultation without any gradual diminution of light, which they ſuppoſe ought to take place. But if we conſider the effect of days and nights near thirty times as long as with us, we may readily grant that the phenomena of vapours and meteors may be very different: perhaps their clouds and rain, if any, may be condenſed into viſible quantities, only during the abſence of the Sun, and if ſo, it is no wonder that we never ſee them. With reſpect to the fixed ſtars, it is plain, that granting the Moon to have an atmoſphere of the ſame nature and quantity as ours, no ſuch effect as a gradual diminution of light ought to take place, at leaſt as to ſenſe. Our atmoſphere is found to be ſo rare at the height of 44 miles, as to be incapable of acting on the rays of light. This height is the 180th part of the Earth's diameter; but ſince clouds are never obſerved higher than four miles, we muſt conclude, that the vapourous or obſcure part is but the 1980th part. The mean apparent diameter

of the Moon is 32′ 12″, or 1932 ſeconds; therefore, the obſcure part of her atmoſphere, when viewed from the Earth, muſt ſubtend an angle of leſs than 1 ſecond, which ſpace is paſſed over by the Moon in leſs than 2 ſeconds of time; a ſpace and time ſo ſhort, that it can hardly be expected that obſervation can determine whether the ſuppoſed obſcuration takes place or not.

The Moon turns round on her own axis once in the time of her periodical revolution. This is evident, becauſe the ſame face or ſide is conſtantly turned towards us. For a ſpectator on the Moon will ſee the Earth carried through every part of the ecliptic in the courſe of one revolution, and as the ſame face of the Moon is conſtantly turned towards the Earth, it muſt be ſucceſſively turned to every part of the ecliptic to which the Earth apparently moves. But if it be ſucceſſively turned to every part of a great circle in the heavens, it muſt revolve on its axis. By this ſlow rotation, it appears, that the inhabitants of the Moon have but one day and night in the courſe of a month.

This

This rotation on its axis is the only uniform motion the Moon has; but its uniformity occaſions a ſeeming irregularity, which is termed her libration. For as the Moon's motion in her orbit was ſhewn to be not uniform, the effect it has in turning her face from the Earth is likewiſe ſubject to the ſame irregularities. For inſtance, in the ſwifteſt part of her revolution, her motion in her orbit turns her face from the Earth ſomething more than her rotation on her axis turns it the other way, and therefore ſhe appears to have a ſmall motion on her axis towards the eaſt, by which ſome of the more weſtern parts are brought into view, and an equal quantity of her eaſtern limb diſappears. In the ſlower part the contrary is ſeen, for then the rotation on her axis prevailing, brings the weſtern parts into view, and the eaſtern diſappear. This is called libration in longitude.

There is another kind of libration which ariſes from the Moon's axis being inclined to the plane of her orbit, by which means ſometimes one of her poles, and ſometimes the other, is inclined towards the Earth. In conſe-

consequence of this we see more or less of her polar regions at different times. This is called libration in latitude.

CHAP. II.

Of the Telescopic Appearances of the Sun and the Planets.

THE Sun is not without spots on his disc, but they are seldom so large as to be seen by the naked eye. When viewed with a telescope, the eye being defended by a piece of coloured or smoked glass, they are found to appear in various forms and numbers. The larger spots, some of which exceed the bulk of the whole Earth, last a considerable time, sometimes three months, before they disappear, at which time they are generally converted into faculæ, or spots which exceed the rest of the Sun in brightness. They are of no constant figure, frequently changing during the time of observation, and sometimes one dividing into several smaller ones. In general they consist of

of a nucleus or central part, much darker than the reſt, which is ſurrounded by a miſtineſs, or ſmoke. The moſt probable opinion concerning them, is, that they are occaſioned by the ſmoke and opake matter thrown out by volcanos or burning mountains of immenſe magnitude, and that when the eruption is nearly ended, and the ſmoke diſſipated, the fierce flames are expoſed, and appear as faculæ, or luminous ſpots. At preſent (anno 1779) they are often ſeen to the number of thirty or more, but there have been periods of more than ſeven years, in which none have been obſerved.

All the ſpots of the Sun have an apparent motion from eaſt to weſt, which is quicker when they are near the central regions than when near the limb. This proves that the Sun is a globe, and likewiſe that he revolves on his axis from weſt to eaſt. The period is obſerved to be about 27 days. From the line of the motion of the ſpots, which is ſometimes ſtrait, but oftener curved or elliptical, it is diſcovered that his axis is not perpendicular to the ecliptic, but inclined, ſo

as to make an angle with the perpendicular of about ſeven degrees.

If the Sun be an ignited body, as we may reaſonably infer from analogy, there can be little doubt but that it is environed with a very denſe atmoſphere. It has been ſuppoſed that this atmoſphere is the cauſe of the aſcent of the vapor which forms the tails of comets, and which is always carried to that part of the heavens which is oppoſite the Sun. But the direction of theſe vapors may perhaps be determined by the action of the particles of light by which they are propelled, and if ſo, the ſuppoſition of ſo extenſive an atmoſphere about the Sun is avoided.

The planet Mercury is at all times ſo near the Sun, that we can only diſtinguiſh with the teleſcope a variation in his figure, which is ſometimes that of a half Moon, and ſometimes a little more or leſs than half. Whence we infer that his form is globular, and that he receives all his light from the Sun.

The planet Venus, when viewed through the teleſcope, has a very pleaſing appearance.

ance. At the time of her greateſt elongation ſhe appears like the Moon in the quadratures, one half of her diſc being enlightened. In the inferior part of her orbit as her elongation decreaſes, the enlightened part becomes leſs, appearing falcated or horned: after paſſing the inferior conjunction, ſhe is again ſeen horned, but the illuminated part then increaſes, and at the greateſt elongation, half her diſc is again ſeen enlightened. In the ſuperior part of her orbit, as her elongation decreaſes, her face becomes more full and round, till the ſuperior conjunction, after which time ſhe again diminiſhes by the ſame gradation as her increaſe was in the former caſe accompliſhed. There is no difficulty in accounting for this variety of phaſes, it being occaſioned by the different poſitions of Venus with reſpect to the Sun and Earth: for as the enlightened face of Venus muſt of courſe be always oppoſite to or facing the Sun, it will be more or leſs viſible to us according to our ſituation at various times.

The ſurface of Venus is diverſified with ſpots like our Moon, by the motion of which

which it is determined, that ſhe revolves on her axis from weſt to eaſt in the ſpace of twenty-three hours. When the air is in a good ſtate for this kind of obſervations, mountains like thoſe in the Moon may be diſcerned, with a very powerful teleſcope.

The face of the planet Mars is always round and full, as his ſuperior ſituation requires, excepting at the time of his quadratures, or elongation of 90 degrees, when a ſmall part of his unenlightened hemiſphere being turned towards us, his diſc appears like the Moon about three days after the full.

By the ſpots on Mars, his diurnal revolution is found to be performed in one day and forty minutes, in the direction from weſt to eaſt. From the ruddy and obſcure appearance of this planet, it is thought that his atmoſphere is much more denſe than thoſe of the other planets.

We have already had occaſion to ſpeak of the ſatellites of Jupiter and Saturn. The annual parallax of theſe planets is not conſiderable enough to bring any ſenſible part of their dark hemiſpheres towards us in any poſition of elongation; conſequently their faces are always round and full.

The telescopic appearance of Jupiter affords a vast field for the curious enquirer. He is in general encircled with one or more obscure belts or bands parallel to the plane of his orbit, and consequently to each other. These are not regular or constant in their appearance. They have been seen to the number of five, and during the time of observation two have gradually disappeared. Sometimes but one is seen; and sometimes, when the number is more considerable, one or more dark spots are formed between the belts, which increase till the whole is united in one large dusky band. The spots of Jupiter are the brighter parts of his surface, and are not permanent, though more so than the belts; yet it is found that they re-appear after certain unequal intervals of time. The remarkable spot, by whose motion the rotation of Jupiter on his axis was determined, disappeared in 1694, and was not seen again till 1708, when it re-appeared exactly in the same place on his surface, and has been occasionally seen ever since.

It has been conjectured that these belts are seas, and that the variations which are observed both in them and the spots are occasioned

fioned by tides, which are differently affected, according to the pofitions of his moons. If an obferver, poffeffed of fkill and patience equal to the tafk, would delineate the phafes of Jupiter for the fpace of a periodical revolution, noting at the fame time the pofitions of his fatellites, this opinion might be either eftablifhed or rejected: but at all events fuch a feries of obfervations could not fail to throw great light on the fubject.

The equatorial diameter of Jupiter exceeds his axis or polar diameter in the ratio of 13 to 12.

The very great diftance of the planet Saturn, and the tenuity of his light, do not permit us to diftinguifh thofe varieties which it is probable are on his furface. The faint appearance of a belt is fometimes feen. The ring which encircles him is inclined to the ecliptic; in confequence of which, its apparent figure is continually varying. When the line of its nodes points directly towards the Earth, the ring, prefenting its edge to the obferver, becomes invifible, and at all other times its figure is that of an oval, which is broader or narrower, accordingly as the line of the nodes is farther from or nearer to the above pofition.

CHAP. XII.

Of the Length of Days and Nights; and of the Seasons.

WE have seen that every planet which is accessible to observation has a revolution on its axis; the intention of which is, undoubtedly, to give alternate night and day to every part of their surfaces. An inclination of the axis of any planet to the axis of its orbit, by causing the length of days and the intensity of heat to vary, occasions a vicissitude of seasons. On this account Jupiter and Mars, whose axes are nearly perpendicular to the planes of their orbits, and consequently parallel to the axes of their orbits, have equal days and nights on every part of their surfaces at the same time: Jupiter's days being four hours and twenty-eight minutes, and that of Mars twelve hours and twenty minutes; the nights being also of the same length: But Venus, whose axis is inclined to that of her orbit in a considerable angle, has

an

an annual change of ſeaſons and length of days. The Earth, for the ſame reaſon, has a ſimilar viciſſitude, in the explanation of which we ſhall preclude the neceſſity of enlarging on the circumſtances of the other planets.

For this purpoſe it will be uſeful to define thoſe imaginary circles, which aſtronomers and geographers have invented for the purpoſes of brevity as well as regularity in their operations.

On the Earth a great circle, ſuppoſed to be drawn at an equal diſtance from each pole, is termed the Equator: leſſer circles drawn parallel to the equator are called Parallels of Latitude; and great circles interſecting the equator at right angles, and conſequently paſſing through the poles, are called Meridians.

In the heavens a great circle, parallel to the equator, is termed the Celeſtial Equator; but the leſſer circles parallel to it are called parallels of declination, and the great circles interſecting it at right angles, and paſſing through the celeſtial poles of the Earth, are called Hour Circles, or circles of right aſcenſion.

The ecliptic is the great circle in the heavens, in which the Sun apparently describes his annual course: lesser circles, drawn parallel to the ecliptic, are called parallels of latitude; and great circles intersecting it at right angles, and consequently passing through its poles, are called celestial meridians.

The horizon is that great circle which divides the visible or upper hemisphere from the lower. If this circle have the eye of the observer for its center, it is called the sensible horizon; but if its center be that of the Earth, it is termed the rational horizon. To this last all astronomical observations are reduced or applied; the former being only considered as one of the parallels of altitude. Lesser circles, parallel to the horizon, are called parallels of altitude, if above, but of depression, if below the horizon, and the great circles intersecting it at right angles are called azimuths.

Latitude on the Earth is the distance between a given place and the equator. It is measured in degrees and minutes of the meridian. In the heavens it is the distance between a given place and the ecliptic, and is measured on the cœlestial meridian.

Longitude

Longitude on the Earth is the diſtance between the meridian paſſing through a given place and the firſt meridian. It is meaſured on the equator from the place of interſection of the firſt meridian to that of the given one. The firſt meridian on the earth is arbitrary; but the Engliſh aſtronomers in general reckon from that which paſſes through the obſervatory at Greenwich. Longitude in the heavens is the diſtance, meaſured on the ecliptic, between a given meridian and that which paſſes through the firſt point of the conſtellation Aries.

Right aſcenſion is the diſtance meaſured on the equator between a given hour circle and that which paſſes through the firſt point of the conſtellation Aries. Declination is the diſtance between a given place and the equator, and is meaſured on one of the hour circles.

The circle which divides the enlightened hemiſphere of a planet from its dark hemiſphere is called the Terminator.

Let NEQS (fig. 44. and 45.) repreſent the Globe of the Earth and C the Sun: then the circles NMS, NMS, &c. will repreſent the meridians interſecting the Equator EQ, at right

angles, and paſſing through the Poles N and S. The lines pp, pp, &c. will repreſent the parallels of latitude; and the line CM will repreſent the plane of the Earth's orbit.

Now it is evident, that it is day at any given place on the globe, ſo long as that place continues in the enlightened hemiſphere; and that when by the diurnal rotation it is carried into the dark hemiſphere it becomes * night. And from the contemplation of figure 45. it appears, that if the poles be ſituated in the terminator, the terminator will divide each of the parallels into two equal parts, and conſequently, ſince the uniform motion of the Earth cauſes any given place to deſcribe equal parts of its parallel in equal times, the days and nights will be equal on every parallel of latitude; that is to ſay, all over the globe, except at the poles, where the Sun will neither riſe nor ſet, but continue in the horizon.

But if, as in figure 44. the axis be not placed in the plane of the terminator, the terminator will divide the equator into two

* Twlight is not here conſidered.

equal

equal parts, but the parallels which are ſituated towards the enlightened pole will have a greater part of their peripheries in the enlightened than in the dark hemiſphere: and ſimilar parallels towards the other pole will have a like greater part of their peripheries in the dark hemiſphere. Whence it follows, that the firſt-mentioned parallels will enjoy longer days than nights, and the contrary will happen to the latter, they having ſhorter days and longer nights; while at the equator the days and nights continue equal. All which is plain by inſpection on the figure, where it is alſo obſervable, that the diſproportion is greateſt in the greater latitudes; and that places, whoſe diſtance from the pole is leſs than that of the pole from the terminator, do enjoy either a conſtant day or conſtant night, the rotation of the Earth never carrying them into the oppoſite hemiſphere.

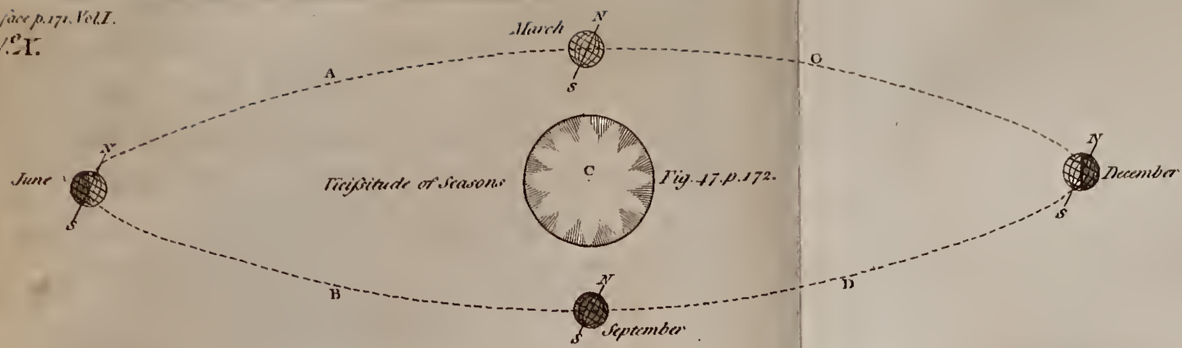
In this poſition of the axis the inhabitants on the one ſide of the equator may be ſaid to enjoy ſummer, and thoſe on the other ſide winter in reſpect to each other; for the long duration of the Sun above the horizon muſt occa-

sion a proportionally greater degree of heat, and his long absence must have the contrary effect.

But this is not all: the greatest altitude of the Sun is at that place which is farthest distant from the terminator. A spectator at G, which is 90° distant from the terminator, will have the sun in the zenith; a spectator at T will see the Sun in the horizon; and, for every intermediate distance, the arc of a great circle comprehended between the terminator and the place of observation will be the measure of the Sun's altitude. Therefore every parallel between G and the enlightened pole will have the meridian altitude of the Sun increased (by the angle NMT) beyond what it would have been had the pole continued in the plane of the terminator: and every place between G and the dark pole will have the Sun's meridian altitude diminished in the same manner. And between S and T his altitude will consequently be negative, or beneath the horizon.

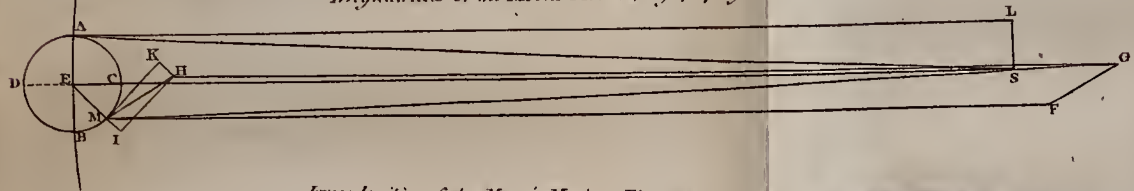
This difference of the altitudes of the Sun is an additional cause of the increase of heat towards the enlightened pole, and the decrease

towards

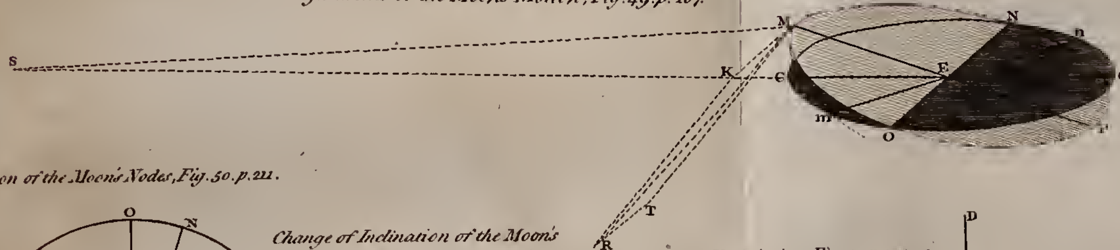


Vicissitude of Seasons Fig. 47. p. 172.

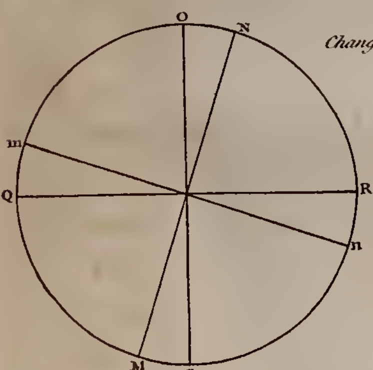
Irregularities of the Moon's Motion, Fig. 48. p. 198.



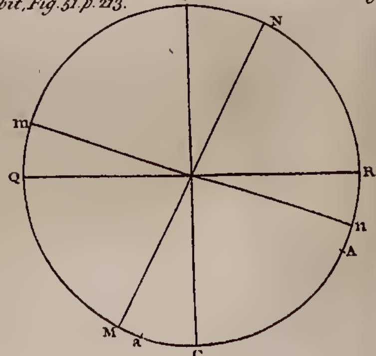
Irregularities of the Moon's Motion, Fig. 49. p. 207.



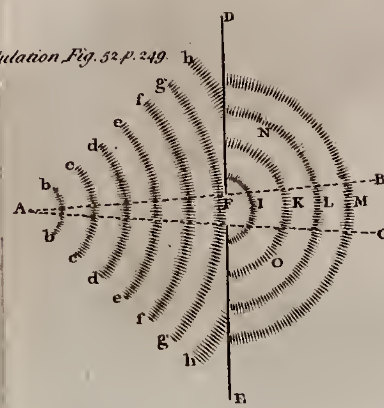
Motion of the Moon's Nodes, Fig. 50. p. 211.



Change of Inclination of the Moon's Orbit, Fig. 51. p. 213.



Undulation Fig. 52. p. 249.



towards the dark pole. For the greater the Sun's altitude the more directly do his rays fall on any ſurface; and in ſurfaces of the ſame magnitude the quantity of light received by each is as the ſine of the angle of obliquity with which the rays fall. This is ſo clear as ſcarce to require an explanation.

Let the line AB (fig. 46.) repreſent a ſurface, on which the column of light NOAB falls perpendicularly. A ſurface AC, of the ſame magnitude, receiving the light obliquely under the angle JCK, will intercept only ſo much as would have fallen on the ſpace A E, and another ſurface A D, receiving the light ſtill more obliquely under the angle LDM, will intercept only ſo much as would have fallen on the ſpace AF. But the ſpaces or lines AE and AF are the ſines of the angles of obliquity JCK and LDM; whence the propoſition is evident.

It remains to be ſhewn, that theſe ſituations of the axis, with reſpect to the terminator, do obtain in the Earth at different times of the year; which being proved, the viciſſitude of ſeaſons muſt follow of courſe.

In

In fig. 47. Let C represent the Sun, ABDG the Earth's orbit, nearly circular, but which being viewed obliquely appears like a long ellipsis, of which let the part BD be supposed nearest the spectator. And let the four circles distinguished by the months March, June, September, and December, represent the Earth in four several parts of her orbit, NS being her axis.

Observation shews, that the axis of the Earth does always preserve very nearly the same position with respect to the fixed stars; being inclined to the axis of her orbit in an angle of about $23\frac{1}{2}$ degrees. It will not therefore preserve the same relative position with respect to the terminator. For suppose the Earth to be in the situation which is distinguished by the month March, her axis at that time is in the plane of the terminator, and consequently the days and nights are equal all over the globe: but when by its annual motion it is carried towards A, the north pole N the axis, still preserving its position or continuing parallel to itself, will advance into the enlightened hemisphere, and

and in the month of June will be $23\frac{1}{2}$ degrees diſtant from the terminator, as in the ſcheme, the ſouth pole being at the ſame diſtance in the dark hemiſphere. Therefore in the month of June the northern parts will enjoy long days and ſummer, while the ſouthern parts have ſhort days and winter.

During the interval between the time of equal days and nights in March, which is called the vernal equinox, and the time at which the day is longeſt in June, which is called the ſummer ſolſtice, the north pole will have deſcribed a quarter of a circle in the enlightened hemiſphere with reſpect to the terminator, and conſequently will be at its greateſt diſtance from it. From that time it will, by deſcribing the other quarter, approach the terminator, the days gradually ſhortening till the Earth arrives at the poſition denoted by the month September, when, the axis again coinciding with the plane of the terminator, the days and nights will be equal. This is called the autumnal equinox. During the next quarter the north pole will deſcribe a quarter of a circle in the dark hemiſphere, and the days will ſhorten

ten till December, when the pole will be just as far within the dark as in June it was in the enlightened hemisphere, which time is called the winter solstice. From the winter solstice to the vernal equinox, the days will lengthen as the pole approaches the terminator; and at the instant in which the axis again coincides with its plane, the natural year, which consists of 365 days, 5 hours, 48 minutes, and 57 seconds, is finished.

It is easy to conceive, by the same explication, using the south pole instead of the north, that the inhabitants of the southern hemisphere have the same vicissitudes, though not at the same time; for it is winter in one hemisphere while it is summer in the other, &c. &c.

As the pole N (fig. 44.) advances in the enlightened hemisphere, the Sun will be in the zenith of a place G, as far distant from the equator as the pole is from the terminator; therefore the greatest latitude at which the Sun can be vertical is 23 $\frac{1}{2}$ degrees. The parallels of latitude on the Earth of 23 $\frac{1}{2}$ degrees N. and S. as also the correspondent parallels of declination

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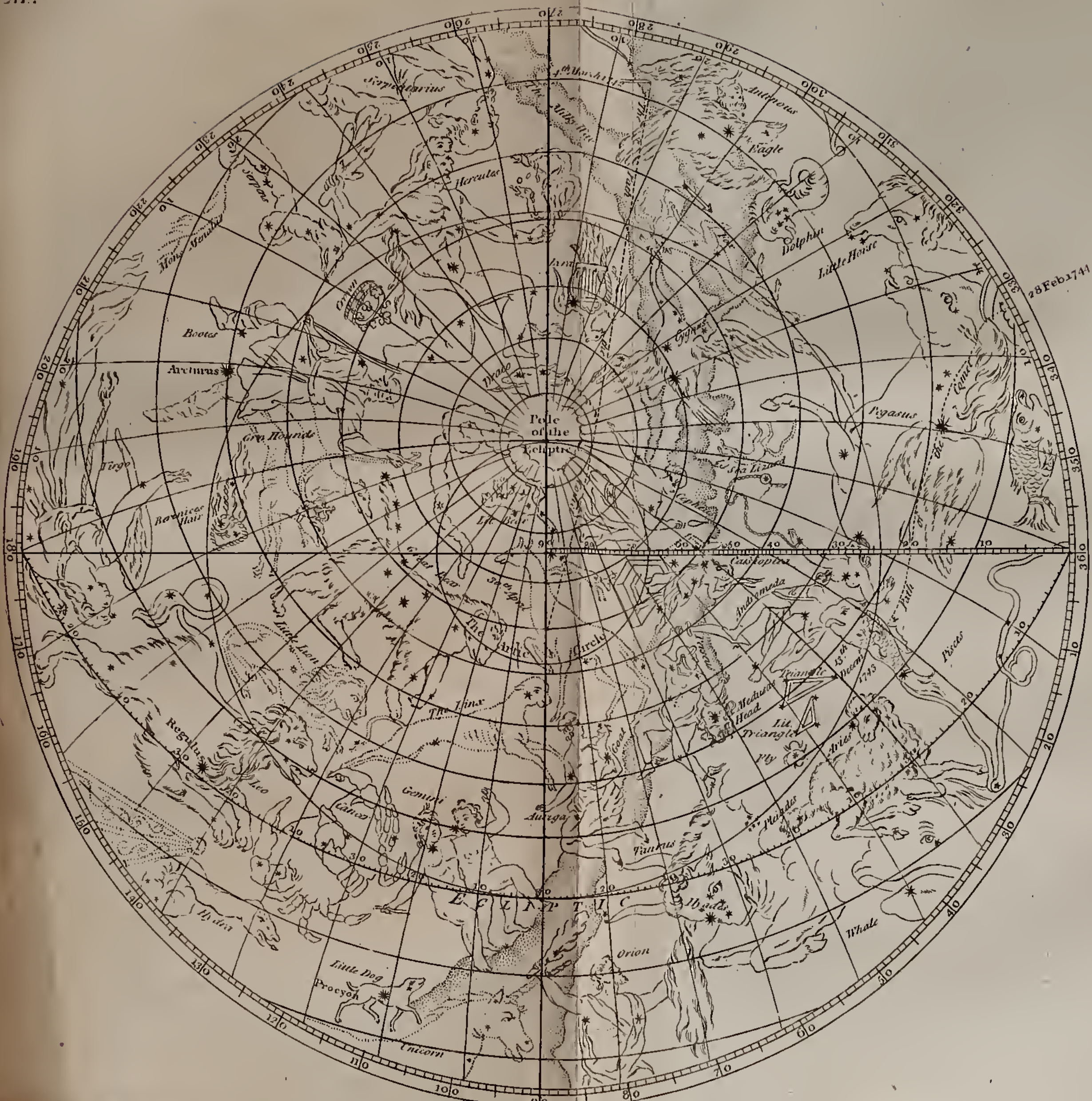
No. VI.

NORTHERN HEMISPHERE.



in the heavens are called the Tropics, becauſe the Sun when he arrives at them does afterwards return towards the equator. The Sun, when he arrives at the north tropic, is juſt entering the ſign Cancer, and when he arrives at the ſouth tropic is juſt entering the ſign Capricorn; for which reaſon the north tropic is called the Tropic of Cancer, and the ſouth tropic the Tropic of Capricorn.

CHAP. XIII.

Of the fixed Stars; and of the Syſtem of the Univerſe.

IT has been mentioned, that the fixed ſtars do always preſerve the ſame poſition with reſpect to each other. This, to ſpeak in general, is true, but there have been obſerved ſeveral variations amongſt them. New ſtars have appeared from time to time; ſeveral of thoſe whoſe places and magnitudes are inſerted in the old catalogues are not now to be found, and ſome of the ſtars have a periodical increaſe and decreaſe of magnitude.

New

New ſtars, to the number of ſix or ſeven, are recorded in ancient authors; but as moſt of thoſe authors were not aſtronomers, and all the accounts ſeem to want the neceſſary preciſion, it cannot at this day be determined whether they were really amongſt the fixed ſtars, or were comets or meteors. Hipparchus, who made the firſt catalogue of the fixed ſtars, is ſaid to have been induced thereunto by an appearance of this kind; but its place in the heavens has not been tranſmitted to us. Of the phenomena of this nature, which have appeared in modern times, the moſt remarkable are the following:

November 8, 1572, Cornelius Gemma attentively conſidered that part of the heavens which is called Caſſiope's Chair, and perceived nothing extraordinary; but the next night, November 9, a new ſtar appeared, with a ſplendor almoſt equal to that of Venus. Tycho Brahe ſaw it on the 11th, from which time it gradually decreaſed, and became inviſible in March, 1574. By accurate obſervations he determined its place to be 9° 17′ longitude from the firſt ſtar in Aries, with

$53° 45'$ north latitude. It has not ſince been ſeen.

September 30, 1604, the ſcholars of Kepler obſerved a ſtar in the right leg of Serpentarius, which was not there the night before. It appeared with a luſtre exceeding that of Jupiter; and like the former decreaſed gradually till January $160\frac{5}{6}$, when it totally diſappeared. By the obſervations of Kepler and others, its place was found to be $7^s\ 20°$ from the firſt ſtar of Aries, with $1°\ 56'$ north latitude.

In 1596, Aug. 3, David Fabricius firſt ſaw that remarkable ſtar in the neck of the Whale, which has ſince been found to increaſe and decreaſe in magnitude periodically. Its period is about 334 days, but it returns not always with the ſame luſtre, neither is it ever ſo ſmall but that it may be diſcerned with a ſix foot teleſcope. It precedes the firſt ſtar of Aries $1°\ 40'$, with $15°\ 57'$ ſouth latitude.

Anno 1600, William Janſonius diſcovered a new ſtar in the neck of the Swan, of about the third magnitude. After continuing ſome years it became ſo ſmall, that ſome were of opinion that it had entirely diſappeared; but

in the years 1657, 1658, and 1659, it again rose to the third magnitude, but soon after decayed, and continues to appear of the fifth or sixth magnitude; situated in $9^s\ 18°\ 38'$ from the first of Aries, with latitude $55°\ 29'$ north.

July 15, 1670, a new star was observed by Hevelius, of the third magnitude, which in October was scarcely visible to the naked eye. In the April following it was rather brighter than at first, yet wholly disappeared about the middle of August. In March 1672 it was again visible, though very small, since which time it has not appeared. Its place was $9^s\ 3°\ 17'$ from the first star of Aries, with latitude $47°\ 28'$ north.

In 1686, G. Kirch discovered a new star, which seldom exceeds the fifth magnitude, and whose period is $404\frac{1}{2}$ days, the greatest part of which time it is invisible. Its re-appearances are very regular; and it is situated about $9^s\ 6°\ 30'$ from the first star of Aries, in latitude $52°\ 40'$ north.

The foregoing are the most remarkable among the variable stars; but many others of smaller magnitude are recorded in the observations of the elder Cassini, Halley, Maraldi, &c.

&c. which brevity does not permit us to enlarge on.

Befides the ftars, there are certain luminous fpots or nebulæ, fome of which are compofed of clufters of fmall telefcopic ftars, whofe blended light illuminates the fpace in which they are fituated; though fingly they are too fmall to be vifible. Of this kind is that great irregular circle or band of light, called the Milky Way, which croffes the ecliptic in Cancer and Capricorn, and is inclined to it in an angle of about fixty degrees. But the other kind of nebulæ appear as luminous fpots through the telefcope, and to the naked eye in general as fmall fixed ftars. The chief are the following:

The firft and moft confiderable is in the middle, between the two ftars on the blade of Orion's fword. It is marked θ by Bayer. Through the telefcope it appears to confift of two contiguous ftars, environed with a very large tranfparent bright fpot, through which they appear, with feveral others. This fpot is in the form of an irregular parallelogram, and was accidentally difcovered to be fuch by Mr. Huygens in 1656.

In 1661, Bullialdus diſcovered another in Andromeda's girdle, which has been omitted in ſeveral catalogues, on account of its ſmallneſs. It ſeems to have no ſtars in it, but appears like a pale cloud, ſending forth a radiant beam towards the north-eaſt, as that in Orion does to the ſouth-eaſt. It precedes in right aſcenſion the northern ſtar in the girdle (marked γ) about 1° 45′.

A third was diſcovered in 1665, by Abraham Ihle. This is ſmall, but very luminous, and emits a ray like the former. Its place at preſent is about ♑ 5°½, with about ½ degree of ſouth latitude.

Dr. Halley in 1677, when he was making a catalogue of the ſouthern ſtars, obſerved that the ſtar in the back of the centaur, marked ω, was nebulous. It appears about the fourth magnitude, and is not very luminous. Its place is about ♏ 6°¾, with about 35° 12′ ſouth latitude.

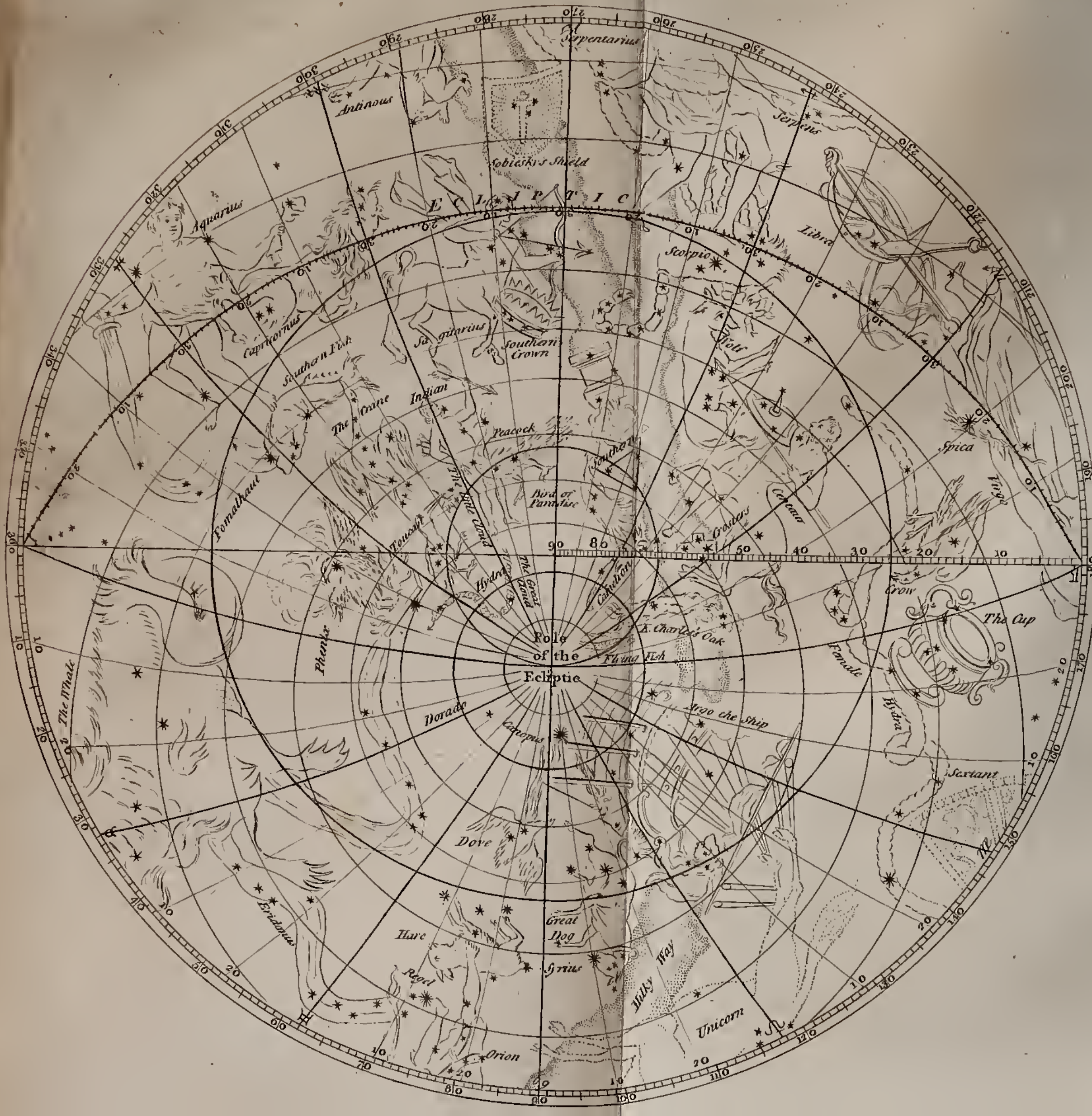
In 1681, G. Kirch diſcovered a nebula preceding the right foot of Antinous. It is a ſmall obſcure ſpot, but has a ſtar, which ſhining through it makes it more conſpicuous.

In

To face p. 181. Vol. I.

Nº XII.

SOUTHERN HEMISPHERE



In 1714, Dr. Halley obſerved a nebula in the conſtellation Hercules, in a right line between the ſtars ζ and η of Bayer. This is but ſmall, but may be ſeen in a clear ſky, if the moon be abſent.

We may rationally ſuppoſe that theſe are not all, but that there may be many not yet obſerved, and perhaps ſome larger than any of theſe, the biggeſt of which are but a few minutes in diameter. But ſince from their want of an annual parallax, it is evident that they are among the fixed ſtars, they cannot fail, notwithſtanding their apparent ſmallneſs, to occupy ſpaces immenſely great; perhaps not leſs than our whole ſolar ſyſtem. In all theſe, ſo vaſt ſpaces, it ſhould ſeem there is a perpetual uninterrupted day.

In conſidering the prodigious magnitude of the ſpace in which the fixed ſtars are placed, it does not ſeem rational to ſuppoſe that ſuch vaſt bodies, as they muſt neceſſarily be, were created for no other purpoſe than to afford us a glimmering light, in the abſence of the Sun. If that were the intention of their exiſtence, why have the teleſcopic ſtars twinkled unſeen till theſe later ages? Certainly

tainly the ſuppoſition agrees very ill with the adequacy of the agent to the effect; which we find to prevail in all the inſtances to which our knowledge extends. We have already ſpoken of the minute objects which, though organized and poſſeſſing ſpecific qualities, are not large enough to come under the obſervation of ſenſe; let us advert to the other limit, and contemplate thoſe magnitudes which exceed the power of our imaginations, by reaſon of their vaſtneſs.

We ſee but a ſmall part of the univerſe. The viſible horizon is ſcarcely more than a degree in diameter, yet that diſtance is the greateſt of which we can form any real conception. Our clear ideas of number enable us to proceed with certainty in our ſpeculations, but our imaginations are not by that means enlarged. Thus we can prove, that the diſtance of the Sun exceeds the diameter of the horizon above eight hundred thouſand times, but cannot from thence form any notion of a diſtance ſo great. We may proceed further, and demonſtrate, that the diſtance of the neareſt fixed ſtar exceeds that of the Sun, in a ratio much beyond this laſt

mentioned;

mentioned; becauſe if it did not, the ſtar would have a ſenſible annual parallax. Not to ſtop here; ſince the number of fixed ſtars is indefinitely great, greater numbers being always ſeen the more perfect the teleſcope; and ſince there is reaſon to think that they are as far diſtant from each other as from us, this laſt diſtance muſt be indefinitely magnified before any ſuppoſition of the diameter of the univerſe can be formed. This magnitude not only exceeds all imagination, but is even beyond the power of numbers! The Creator of the fabric alone can comprehend the infinite expanſion. Here it is that our obſervations fail us, and our knowledge is of neceſſity reduced to hypotheſis. That which is generally received is founded on the following analogical proof.

It muſt be remembered, that when ſpeaking of parallax, it was ſhewn that the baſe between the two ſtations of an obſerver is always ſeen from the object under the ſame angle as the parallax itſelf. The neareſt fixed ſtar has no annual parallax; therefore the diameter of the annual orbit, if viewed from the neareſt fixed ſtar, would ſubtend no ſen-

ſible angle, and à fortiori, the Sun itſelf would appear no more than as a luminous point; that is to ſay, as a fixed ſtar. Whence it follows, that the ſtars muſt equal the Sun in bulk; or, in other words, that they are ſuns. The ſame argument of the inſenſibility of the parallax, not to mention the imbecility of their light, will prove that the planets could not be viſible at the diſtance of a fixed ſtar. It is therefore no derogation from the probability of every fixed ſtar's being accompanied by a ſyſtem of planets, to ſay we do not ſee them; ſince that is proved to be impoſſible, even granting them to exiſt. Conſequently the moſt rational hypotheſis of the final purpoſe of ſo many Suns is, that they are ordained to diſtribute light and heat to an immenſe number of worlds that attend on them.

BOOK

BOOK I.

SECT. IV.

Of the general Effects of Gravitation.

CHAP. I.

Of the Physical Causes of the Cœlestial Motions.

TO explain the physical causes of the cœlestial motions, we shall assume the following postulates from the often quoted Principia of Sir Isaac Newton, to which we refer our mathematical readers for their demonstration.

If the * squares of the periodical times of bodies which revolve in similar orbits, whose centers are similarly placed, and which, singly,

* Princip. 4. l. 1.

describe

describe equal areas in equal times, be to each other in the same direct proportion as the cubes of their mean distances from their centers, the centripetal forces will be reciprocally as the squares of the mean distances.—And the contrary; if the centripetal forces be reciprocally, &c.

If a * body revolve in an orbit, not circular, describing equal areas about a center, and the centripetal force be reciprocally as the square of the distance of the body from the center, it will pass from one apsis to the other precisely in half a revolution; and consequently the line of the apsides will constantly retain the same position, or be immoveable. And the contrary.

If a body revolve in an orbit, not circular, describing equal areas about a center, and the centripetal force be reciprocally in the proportion of some power greater than the square and less than the cube of the distance, it will pass from one apsis to the other in more than half a revolution; such a body may be conceived to revolve in an ellipsis, whose longest diameter

* Princip. 45. l. 1.

or

or line of the apſides continually moves in conſequentia, or in the ſame direction as the body itſelf. And the contrary.

If a body revolve in an orbit, not circular, deſcribing equal areas about a center, and the centripetal force be reciprocally in the proportion of ſome power leſs than the ſquare of the diſtance, it will paſs from one apſis to the other in leſs than half a revolution. Such a body may be conceived to revolve in an ellipſis, whoſe longeſt diameter or line of the apſides continually moves in antecedentia, or in a direction contrary to that of the body itſelf. And the contrary.

Theſe being premiſed, it follows that,

The forces by which the ſatellites of Jupiter are continually deflected from right-lined motions, and retained in their orbits, are directed to the center of Jupiter; and are reciprocally as the ſquares of the diſtances from that center.

For they, ſingly, deſcribe equal areas in equal times about the center; and the ſquares of their periodical times are in the direct proportion of the cubes of their diſtances.

The

The ſame is true of the ſatellites of Saturn; and for the ſame reaſons.

The forces, by which the primary planets are continually deflected from right-lined motions, and retained in their orbits, are directed to the Sun, and are reciprocally as the ſquares of the diſtances from his center.

For they, ſingly, deſcribe equal areas in equal times about that center; and the ſquares of their periodical times are in the direct proportion of the cubes of their diſtances. This latter part of the propoſition is very accurately demonſtrated from the quieſcence of their apſides: for the leaſt variation from the duplicate ratio would occaſion a perceptible motion of the apſides, which in a number of revolutions would be very conſiderable.

The force by which the Moon is retained in its orbit, is directed to the center of the Earth, and is reciprocally as the ſquares of the diſtances from that center.

For the Moon deſcribes equal areas in equal times; and her apſides may be ſaid to be quieſcent. The ſmall motion of three

degrees

degrees and three minutes in conſequentia in each revolution being occaſioned, as will be ſhewn, by the action of the Sun, need not here be regarded.

The force by which the Moon is continually deflected from right-lined motion, and retained in its orbit is the ſame with that force which we call gravitation.

The mean diſtance of the Moon from the center of the Earth is found to be about 60 ſemidiameters of the Earth; her periodical revolution is performed in 27 days, 7 hours, 43 minutes; and the French, by admeaſurement, found the circumference of the Earth to be 123,249,600 Paris feet; therefore the circumference of the Moon's orbit is 60 times that quantity. Now, in very ſmall arcs, ſuppoſe De, which do not ſenſibly differ from right lines, the verſed ſine Dd, will expreſs the quantity or effect of the centripetal force. (See fig. 29.) And the verſed ſine of the arc which the Moon deſcribes with her mean motion in one minute of time, being $15\frac{1}{12}$ Paris feet is, conſequently, the ſpace through which ſhe would fall by her centripetal force, if the projectile force were intirely deſtroyed.

To find the effect of this centripetal force at the ſurface of the Earth, it muſt be increaſed in the reciprocal proportion of the ſquares of the diſtances.

As the ſquare of the diſtance at the ſurface of the Earth from the Earth's center (1 ſemidiameter)	1,
Is to the ſquare of the diſtance of the Moon from the Earth's center (60 ſemidiameters) -	3600,
So is the centripetal force at the Moon, expreſſed by the ſpace deſcribed in one minute, -	$15\frac{1}{12}$ feet,
To the centripetal force at the ſurface of the Earth, or ſpace deſcribed in one minute, -	54300 feet.

Becauſe the centripetal force acts conſtantly (and equally at equal diſtances) theſe motions will be uniformly accelerated; and becauſe the ſpaces deſcribed by any uniformly accelerated motion taken from the beginning, are as the ſquares of the times, we may find what ſpace the Moon would fall through in a ſecond if near the ſurface of the Earth; thus,

As

As the ſquare of one minute
or 60 ſeconds, - - 3600

Is to the ſpace deſcribed in
that time, - - 54300 feet,

So is the ſquare of one ſecond, 1

To the ſpace deſcribed in that
time, - - - $15\frac{1}{12}$.

But this is preciſely the ſpace which bodies falling by the force of gravity do deſcribe in a ſecond. Therefore, the force by which the Moon is retained in its orbit is the ſame as the force by which terreſtrial bodies are attracted towards the Earth (by the firſt and ſecond rules of philoſophizing).

The ſatellites of Jupiter and Saturn do gravitate towards their primaries, and the primary planets, together with their ſatellites, do gravitate towards the Sun.

For their revolutions are effects of the ſame kind as the revolution of the Moon about the Earth, and therefore depend on the ſame cauſe; more eſpecially ſince it is ſhewn, that the centripetal forces which occaſion thoſe revolutions vary at different diſtances, according to the ſame law as gravity is proved to

vary

vary at different diſtances from the center of the Earth.

Gravity then is given in all the planets. For there is no doubt but Mars, Venus, and Mercury are bodies of the ſame kind as Jupiter and Saturn. And ſince all attraction is mutual, Jupiter muſt gravitate towards his ſatellites, Saturn towards his ſatellites, the Earth towards the Moon, and the Sun towards all the planets.

The gravity which tends to or reſpects any planet is inverſely according to the ſquares of the diſtances of places from its center.

Therefore, all the planets do mutually gravitate towards each other: and hence Jupiter and Saturn, when near the conjunction, do ſenſibly diſturb each other's motions. The Sun diſturbs the lunar motions, and the Sun and Moon diſturb the ſea, occaſioning tides, as will be ſhewn.

All bodies do gravitate to every one of the planets; and the weights of bodies on any planet at equal diſtances from its center, are as their maſſes or quantities of matter.

All bodies deſcend to the Earth from equal heights, allowance being made for the re-

ſiſtance

ſiſtance of the air, in equal times; their forces are therefore as their quantities of matter. If theſe terreſtrial bodies be ſuppoſed to be carried up to the orb of the Moon, they would, from what has already been ſhewn, deſcend to Earth in the ſame time as the Moon would, if her projectile motion were deſtroyed: and it cannot be doubted, but the nature of gravity is the ſame in the planets as in the Earth. Moreover, ſince the forces which retain the ſatellites of Jupiter in their orbits are in a conſtant ratio to the diſtances, namely as the ſquares, it is plain, that if let fall at equal diſtances from his center, they would deſcribe equal ſpaces in equal times, as is the caſe with heavy bodies near the Earth, and their weights would be as their quantities of matter. The ſame reaſoning is applicable to the ſatellites which revolve about Saturn, and to the primaries, with their ſatellites, which revolve about the Sun. And ſince the action of the Sun on a ſecondary ſyſtem, or planet accompanied by moons, does not diſturb their motions, while the ſeveral bodies remain at equal diſtances from his center, except ſo far

as the direction of his action is not in parallel lines, it follows that his action on the several parts of such secondary system is accurately according to their masses.

Gravitation is universal, and its force towards any particular body is in proportion to the quantity of matter in that body.

For the weight or gravitation of any parcel of matter or planet A, towards another B, is in proportion to its quantity, and reaction is equal to action. Consequently, if the quantity of matter in A be increased or decreased in any given proportion, its reaction on B, that is to say, the gravitation of B towards A, will be increased or decreased in the same ratio.

Hence the masses or quantities of matter in those planets which are accompanied by others may be found. For the diameters of the orbits of their attendants, and the periodical times being known, we may find their centripetal forces as was before instanced in the Moon; which, by the inverted proportion of the square of the distance may be found for any distance. Thus we may com-

pare

pare the centripetal forces of the planets towards the Sun, and of Jupiter and Saturn's Moons towards their primaries, with the centripetal force of the Moon towards the Earth, and their respective masses will be as those forces. Their diameters being known, we can compare the weights of bodies on their respective surfaces; and from their solid contents or bulks compared with their masses, we can find their densities. By these principles it appears, that the masses of the Sun, Jupiter, Saturn, and the Earth are respectively as 1, $\frac{1}{1067}$, $\frac{1}{3021}$, and $\frac{1}{169282}$; the weights of bodies at their surfaces respectively as 1000, 943, 529, 435; and their densities respectively as 100, $94\frac{1}{2}$, 67, and 400. From which it is seen, that the weights of bodies on the surfaces of the planets is not considerably different, and that the densities of the planets which are nearest the Sun are the greatest, for the purpose, no doubt, of accommodating them to the greater degree of heat; for dense matter, in general, requires a greater heat for the operations of nature than that which is more rarefied.

And if the cœleſtial ſpaces be not abſolutely vacuous, but are poſſeſſed by ſome very rare medium, that medium muſt reſiſt the motions of the heavenly bodies in a ſmall degree: it is therefore neceſſary that the ſmaller planets ſhould be denſer than the larger, in order that the reſiſtances may be equal, and their relative motions leſs diſturbed from that cauſe.

C H A P. II.

Of the Irregularities which ariſe from the mutual Gravitations of the Planets.

GRAVITY being thus ſhewn to be univerſal, and to act according to the ſame invariable law in all bodies, in proportion to their maſſes; the cœleſtial motions may be deduced from its mode of action by the method of ſyntheſis. Hence it is collected, that if the Sun were at reſt, and the planets did not mutually gravitate towards each other, they would deſcribe ellipſes, the common focus of which would be the Sun. But ſince they

they do mutually act on the Sun, and on each other, it is proved that the Sun is perpetually moved about the center of gravity of all the planets, which center is the common focus of their orbits. This center, by reaſon of the Sun's very great bulk, can, in no ſituation, exceed the diſtance of his ſemidiameter from his ſurface. Some ſmall irregularities ariſe from theſe mutual actions, but much leſs than would enſue if the Sun were at reſt, or not ſubject to the reaction of the other planets. The irregularities in the motions of the primary planets are hardly conſiderable enough to come under our obſervation: thoſe of the Moon, on account of her nearneſs to us, and for other cauſes, have ever been ſufficiently great to embarras the aſtronomical world. We ſhall therefore explain the latter, and apply the explanation to the former, which are effects of the ſame kind.

If the actions of the Sun upon the Earth and Moon were equal upon each, according to their maſſes, and tended to produce motions in parallel directions, their relative motions would be the ſame as if no ſuch forces acted upon them. But theſe forces vary, both

in quantity and direction, according to the various relative situations of the Earth and Moon.

Let the point S (fig. 48.) represent the Sun, E the Earth, and ADBC the orbit of the Moon. Then, if the Moon be at the quadrature A, the distances ES and AS of the Earth and Moon from the Sun, being equal, their gravities towards S will also be equal, and may be represented by those lines ES and AS. Draw the line AL parallel and equal to ES; and join LS, which will be parallel to AE. The force AS may be resolved into the two forces AL and AE; of which AL, by reason of its parallelism and equality to ES, will not disturb their relative motions or situation: but the force AE, conspiring with that of gravity, will add thereto, and cause the Moon to fall farther below the tangent of her orbit than she would if no such disturbing force existed. Therefore, at or near the quadratures, the Moon's gravity towards the Earth is increased more than according to the regular course, and her orbit is rendered more curve.

When

When the Moon is at the conjunction C, the diſtances ES and CS not being equal, the Moon's gravitation towards the Sun exceeds that of the Earth in the ſame proportion as the ſquare of ES exceeds the ſquare of CS. And becauſe the exceſs acts contrary to the direction of the Moon's gravity towards the Earth, it diminiſhes the effect thereof, and cauſes the Moon to fall leſs below the tangent of her orbit than ſhe would if no ſuch diſturbing force exiſted. A like and very nearly equal effect follows, when the Moon is at the oppoſition D; by the Earth's gravitation towards the Sun being greater than that of the Moon; whence their mutual gravity is diminiſhed as in the former caſe. Therefore, at or near the conjunction or oppoſition, the Moon's gravity is diminiſhed, and her orbit is rendered leſs curve.

It is found, that the force added to the Moon's gravity at the quadratures, is to the gravity with which ſhe would revolve about the Earth in a circle at her preſent mean diſtance, if the Sun had no effect on her motion, as 1 to $178\frac{29}{40}$: and that the force ſubducted from her gravity at the conjunction

or oppoſition is about double this quantity. The influence of the Sun, then on the whole, increaſes the Moon's diſtance from the Earth, and augments her periodical time; and ſince this influence is moſt conſiderable when the Earth is neareſt the Sun, or in its perihelium, her periodical time muſt then be the greateſt, as appears likewiſe from obſervation.

To ſhew the effect of the Sun in diſturbing the Moon's motion at any ſituation between the conjunction and one of the quadratures, ſuppoſe at M (fig. 48.) let ES repreſent the Earth's gravity towards the Sun. Draw the line MS, which continue towards G. From M ſet off MG, ſo that MG may be to ES, as the ſquare of the Earth's diſtance ES, is to the ſquare of the Moon's diſtance MS; and MG will repreſent the Moon's gravity towards the Sun. From M draw MF parallel and equal to ES; join FG, and draw MH parallel and equal to FG. The force MG may be reſolved into MF and MH; of which MF, by reaſon of its paralleliſm and equality to ES, will not diſturb the relative motions or ſituation of the Moon and Earth. MH then is the diſturbing force. Draw the tangent MK to the

the Moon's orbit, and continue the radius EM towards I. Draw HI parallel to KM, and interfecting MI in I, and complete the parallelogram by drawing HK parallel to IM, and interfecting MK in K. The force MH may be refolved into MI and MK; of which MI affects the gravity, and MK the velocity of the Moon. When the force MH coincides with the tangent; that is, when the Moon is 35° 16′ diftant from the quadrature, the force MI, which affects the gravity, vanifhes; and when the force MH concides with the radius, that is, when the Moon is either in the conjunction or quadrature, the force MK vanifhes. Between the quadrature and the diftance of 35° 16′, from it, the line or force MH falls within the tangent, and confequently the force MI is directed towards E, and the Moon's gravity is increafed: but, at any greater diftance from the quadrature, the line MH falls without the tangent, and the force MI is directed from E, the Moon's gravity being diminifhed. It is evident that the force MK is always directed to fome point in the line which paffes through the centers of the Sun and Earth;

Earth; therefore it will accelerate the Moon's motion, while ſhe is approaching towards that line, or the conjunction, and ſimilarly retard it as ſhe recedes from it, or approaches towards the quadrature, by conſpiring with her motion in the one caſe, and ſubducting from it in the other.

As the Moon's gravity towards the Sun at the conjunction is diminiſhed by a quantity which is as the difference of the ſquares of their diſtances; and as this difference, on account of the very great diſtance of the Sun, is nearly the ſame when the Moon is at the oppoſition, the mutual tendency to ſeparate, or diminution of gravity, will be very nearly the ſame. Whence it eaſily follows, that all the irregularities which have been explained as happening between the quarters and conjunction muſt in like circumſtances take place between the quarters and the oppoſition.

If the Moon revolved about the Earth in a circular orbit, the Sun's diſturbing influence being ſuppoſed not to act, then this influence being ſuppoſed to act would convert the orbit into an ellipſis. For the increaſe of gravity renders it more curve at the

quadratures,

quadratures, by causing the Moon to fall further below the tangent; and the diminution of gravity, as well as the increased velocity, renders the orbit less curve at the conjunction and opposition, by causing the Moon to fall less below the tangent in a given time. Therefore an ellipsis would be described, whose lesser or more convex parts would be at the quadratures, and whose longest diameter would pass through them. Consequently the Moon would be farthest from the Earth at the quadratures, and nearest at the conjunction and opposition. Neither is it strange that the Moon should approach or come nearer to the Earth at the time when her gravity is the least, since that approach is not the immediate consequence of the decrease of gravity, but of the curvity of her orbit near the quadratures; and in like manner, her recess from the Earth at the quadratures does not arise immediately from her decreased gravity, but from the velocity and direction acquired at the conjunction or opposition.

But as the Moon's orbit is, independant of the Sun's action, an ellipsis, these effects take

take place only as far as circumſtances will allow.

The Moon's gravity towards the Earth being thus ſubject to a continual change in its ratio, her orbit is of no conſtant form. The law of her gravity being nearly in the inverſe proportion of the ſquares of her diſtances, her orbit is nearly a quieſcent ellipſis; but the deviations from this law occaſion her apſides to move direct or retrograde, according as thoſe deviations are in defect or exceſs. Aſtronomers, to reduce the motion of the apſides to computation, do ſuppoſe the revolving body to move in an ellipſis, whoſe tranſverſe diameter or line of the apſides revolves at the ſame time about the focus of the orbit. When the Moon is in the conjunction or oppoſition, the Sun ſubducts from her gravity, as has been ſhewn, and that the more the greater her diſtance is from the Earth, ſo that her gravity decreaſes in a leſs proportion than the inverted ratio of the ſquare of her diſtance, and conſequently her apſides then move in conſequentia, or direct. In the quadratures the Sun adds to her gravity, and that the more the greater her diſ-

tance from the earth, ſo that her gravity decreaſes in a leſs proportion than the inverted ratio of the ſquare of her diſtance, and conſequently her apſides then move in antecedentia, or retrograde. But becauſe the action of the Sun ſubducts more from the Moon's gravity in the conjunction and oppoſition than it adds to it in the quarters, the direct motion exceeds the retrograde, and at the end of each revolution the apſides are found to be advanced according to the order of the ſigns.

If the plane of the Moon's orbit coincided with that of the ecliptic, theſe would be the only irregularities ariſing from the Sun's action; but becauſe it is inclined to the plane of the ecliptic in an angle of about five degrees, the whole diſturbing force does not act upon her motion in her orbit, a ſmall part of it being employed to draw her out of its plane into that of the ecliptic.

Of the forces MK and MI, (fig. 48.) which diſturb the Moon's motion, MI being always in the direction of the radius, can have no effect in drawing her out of the plane of her orbit. And if the force MK really

really coincided with the tangent, as we (neglecting the ſmall deviation ariſing from the obliquity of the Moon's orbit) have hitherto ſuppoſed, it is evident that its only effect would be that of accelerating or retarding the Moon's motion, without affecting the plane of her orbit. But becauſe that force is always directed to ſome point in the line which paſſes through the centers of the Sun and Earth, it is plain that it can coincide with the tangent only when that line is in the plane of the Moon's orbit; that is to ſay, when the nodes are in the conjunction and oppoſition. At all other times the force MI muſt decline to the northward or ſouthward of the tangent, and compounding itſelf with the Moon's motion, will not only accelerate or retard it, according to the circumſtances before explained, but will likewiſe alter its direction, deflecting it towards that ſide of the orbit on which the point, towards which the force MI tends, is ſituated. This deflection cauſes the Moon to arrive at the ecliptic either ſooner or later than ſhe would otherwiſe have done; or, in other words, it occaſions the interſection of her orbit with the

ecliptic to happen in a point of the ecliptic, either nearer to, or further from, the Moon, than that in which it would have happened if ſuch deflection had not taken place.

To illuſtrate this, let the elliptical projection COQN (fig. 49.) repreſent a circle in the plane of the ecliptic, MOPN the Moon's orbit, interſecting the ecliptic in the nodes N and O. Suppoſe the Moon to be in the northern part of her orbit at M, and moving towards the node O; the diſturbing force MK, which tends towards a point in the line SE to the ſouthward of the tangent MT, will be compounded with the tangental force, and will cauſe the Moon to deſcribe the arc Mm, to which MR is tangent, inſtead of the arc MO; whence the node O is ſaid to be moved to m. In like manner may the motion of the nodes be explained in any other ſituation.

This motion evidently depends on a twofold circumſtance, namely, the quantity and direction of the force MK. If the force MK be increaſed, its direction remaining the ſame, it will deflect the curve of the Moon from her orbit in a greater degree; and on the other

other hand, if its direction be altered, ſo as to approach nearer to a right angle with the tangent, it will cauſe a greater deflection, though its quantity remain the ſame. When the Moon is in the quadratures, the force MK vaniſhes, as has been ſhewn, conſequently the nodes are then ſtationary. When the Moon is at the octant, or forty-five degrees from the quadrature, the force MK is greateſt of all, and therefore the motion of the nodes is then moſt conſiderable, as far as it depends on the quantity of MK. But the direction of this force in like circumſtances depends on the ſituation of the line of the nodes. If the line of the nodes coincides with the line paſſing through the centers of the Sun and Earth, the force MK coincides with the tangent of the Moon's orbit, and the nodes are ſtationary. And the farther the node is removed from that line, the farther is that line removed from the plane of the Moon's orbit; till the line of the nodes is in the quadratures, at which time the line paſſing through the centers of the Sun and Earth, makes an angle with the plane of the Moon's orbit equal to its whole inclination, or five degrees.

degrees: consequently the angle formed between MK and the tangent in like circumstances is then greatest, MK being directed to a point in a line which is further from the plane of the Moon's orbit than at any other time, and of course the motion of the nodes is then most considerable.

To determine the quantity and direction of the motion of the nodes, suppose the Moon in the quarter preceding the conjunction, and the node towards which she is moving to be between her and the conjunction: in this case her motion is directed to a point in the ecliptic, which is less distant than the point towards which the force MK is directed: the force MK then, compounding with the Moon's motion, causes it to be directed to a point more distant than it would otherwise have been; that is to say, the node, towards which the Moon moves, is moved towards the conjunction. When the Moon has passed the node, its course is directed to the other node, which is a point in the ecliptic more distant than the point to which MK is directed, and therefore MK, compounding with her

motion, caufes it to be directed to a point lefs diftant than it would otherwife have been; fo that in this cafe likewife, the enfuing node is moved towards the conjunction. After fhe has paffed the conjunction the force MK ftill continues to deflect her courfe towards the ecliptic, and confequently the motion of the node is the fame way till her arrival at the quadrature. Suppofe again, the Moon to be at the conjunction, and the node towards which fhe is moving to be between her and the quadrature. In this cafe the force MK compounding with the Moon's motion, caufes her to move towards a point in the ecliptic lefs diftant than fhe would otherwife have done, fo that the enfuing node is brought towards the conjunction. When the Moon has paffed the node, the force MK ftill continuing to deflect her courfe towards the fame fide of her orbit, produces a contrary effect, namely, as it before occafioned her to converge to the ecliptic, fo it now caufes her to diverge from it, and her motion in confequence tends continually to a point in the ecliptic more

more diſtant than it would otherwiſe have done: the enſuing node in this inſtance being alſo brought towards the conjunction.

As the diſturbing forces are very nearly the ſame in the half of the Moon's orbit, which is fartheſt from the Sun, this laſt paragraph is true, when ſhe is in that part of her orbit, if the word oppoſition be every where inſerted inſtead of the word conjunction.

Whence it is eaſy to deduce this general rule, that when the Moon is in that part of her orbit neareſt the Sun, the node towards which ſhe is moving is made to move towards the conjunction: and when ſhe is in that part of her orbit fartheſt from the Sun, the node towards which ſhe is moving is made to move towards the oppoſition.

Suppoſe the Moon at Q, (fig. 50.) or the quadrature preceding the conjunction, then the enſuing node, if at 90° diſtance, or at the conjunction C, will be ſtationary, but if it be at a greater or leſs diſtance, it will be brought towards C, (by the general rule.) Thus, if the nodes be in the poſition MN, the enſuing node M, being at a leſs diſtance from Q than 90°, will move towards C, or

 direct,

direct, while the Moon moves through the arc QM; after which N becomes the ensuing node, and likewise moves towards the conjunction C, or retrograde during the Moon's motion through the arc MR. And because the arc MR exceeds QM, the retrograde motion exceeds the direct. Again, if the nodes be in the position nm, the ensuing node n being at a greater distance from Q than 90°, will move towards C, or retrograde, during the Moon's motion through the arc Qn; after which the node m becomes the ensuing node, and likewise moves towards the conjunction C, or direct, during her motion through the arc nR. And because the arc Qn exceeds nR, the retrograde motion here also exceeds the direct. If the nodes be in the quadratures QR, the ensuing node R moves towards C, or retrograde, during the Moon's motion through the arc QR, or almost the whole semi-orbit. The same may be shewn in the other half of the orbit ROQ; and therefore, in every revolution of the Moon, the retrograde motion of the nodes exceeds the direct; and, on the

whole,

whole, the nodes are carried round, contrary of the order of the ſigns.

The line of the conjunction is by the Earth's annual motion brought into every poſſible ſituation with reſpect to the nodes in the courſe of a year, independant of their own proper motion, which occaſions the change of ſituation to be performed in about nineteen days leſs.

The inclination of the Moon's orbit being the angle which her courſe makes with the plane of the ecliptic, it is evident from what has been ſaid, that this angle is almoſt continually changing. Suppoſe the line of the nodes, by its retrograde motion, to leave the conjunction C, (fig. 51.) and become in the ſecond and fourth quarters as in the poſition MN, and the Moon to move from the node M to the node N: then, becauſe the enſuing node N moves (by the general rule) towards the conjunction C, while the Moon is in the nearer half of her orbit, the Moon's courſe muſt be continually more and more inflected towards the ecliptic, till her arrival at R. This inflection in the firſt 90°, or MA from M, prevents her diverg-

ing ſo much from the ecliptic as ſhe would otherwiſe have done; that is to ſay, it diminiſhes the angle of her inclination. From A to R her courſe begins to converge towards the ecliptic, and this convergence is increaſed by the inflection which in the preceeding 90° prevented her divergence: in the arc AR then her inclination is increaſed. During her motion from R to N, the node is moved towards the oppoſition O, and conſequently the angle of the Moon's courſe to N is rendered leſs than it would have been if the node has not moved; or, in other words, her inclination is diminiſhed. And becauſe the arc MA added to the arc RN is greater than the arc AR, the inclination at the ſubſequent node is leſs than at the precedent node; and the ſame may be ſhewn in the other half revolution NQM. Therefore, while the nodes are moving from the conjunction and oppoſition to the quadratures, the inclination of the Moon's orbit, on the whole, diminiſhes in every revolution till they arrive in the quadratures, at which time it is leaſt of all. When the line of the nodes has paſſed the quadratures, and is in the

the firſt and third quarters, as in the poſition mn, it is eaſily ſhewn by the ſame kind of argument, that the inclination is increaſed while the Moon paſſes from m to Q, then diminiſhes for the remainder of the firſt 90° or Q a, and afterwards increaſed for the other 90° or a n: and the ſame may be proved for the other half revolution nRm. Conſequently, while the nodes are moving from the quadratures to the conjunction and oppoſition, the inclination is increaſed by the ſame degrees as it before was diminiſhed, till they arrive at the conjunction and oppoſition, at which time it returns to its firſt quantity, being then greateſt of all.

The line of the nodes in the courſe of one entire revolution, with reſpect to the Sun, is twice in the quadratures and twice in the conjunction and oppoſition. Therefore the inclination of the Moon's orbit to the ecliptic is diminiſhed and increaſed by turns twice in every revolution of the nodes.

All the irregularities of the Moon's motion are a little greater when ſhe is in the half of her orbit neareſt the Sun than when ſhe is in the other half; the reaſon of which is,

 that

that the difference between the ſquares of the Moon's and Earth's diſtances from the Sun is greater, after the rate, in the former than in the latter caſe at equal elongations from the quadrature, and conſequently the diſturbing forces thence ariſing muſt be more conſiderable.

Although the Moon in reality revolves about the common center of gravity between her and the Earth, and not about the Earth itſelf, and conſequently their motions and irregularities are ſimilar, and not confined to the Moon alone; yet it may be eaſily conceived that our concluſions are the ſame, when, for the ſake of conciſeneſs, we ſuppoſe one of the two bodies to be quieſcent, and the other to revolve about it.

Irregularities of the ſame kind take place among the primary planets by their mutual actions on each other, but they are almoſt inconſiderable. Hence the apſides of the inferior planets are found to move in conſequentia, but ſo very ſlowly, that ſome doubt whether they move at all. If the apſides of Mars move 35′ in a century, thoſe of the Earth, Venus, and Mercury, will, by

by calculation, move 18′ 36″, 11′ 27″, and 4′ 29″ in the ſame time. The actions of the inferior planets on each other are very minute, on account of the ſmallneſs of their bulks; but thoſe of Jupiter and Saturn are not altogether inſenſible. When Jupiter is between the Sun and Saturn, his whole attraction acts upon Saturn, and increaſes his gravity towards the Sun. This is found, by comparing the reſpective maſſes of Jupiter and the Sun, and the reſpective ſquares of their diſtances from Saturn, to be equal to $\frac{1}{204}$ of the Sun's action upon Saturn: which conſequently deflects him from his orbit ſo much, that it is even obſerved by aſtronomers. Saturn, on the other hand, at the conjunction, acts upon Jupiter and the Sun in the ſame direction, and therefore diſturbs their relative poſition only ſo far as his actions on each are not equal. The difference of theſe actions is found by the ſame principles to be $\frac{1}{1923}$ of Jupiter's whole gravity.

CHAP.

CHAP. III.

Of the Figures of the Planets; the Preceſſion of the Equinoxes, and the Nutation of the Poles.

A Maſs of fluid matter will, by its gravity, form itſelf into a ſphere. For if the whole maſs be conceived to be divided into a number of ſimilar pyramids or columns, which terminate in the center of gravity, and one of theſe columns be longer than the reſt, its greater weight will cauſe it to move or ſubſide towards the center, till its weight, and conſequently height, be equal to that of the other columns. The ſame is true of any other eminences or longer columns. Therefore, when all the ſubſidences are effected, and the maſs is at reſt, its form will be that of a ſolid, whoſe ſurface is every where equidiſtant from its center. And this is the property of a ſphere.

This takes place in a maſs whoſe parts preſerve the ſame ſituation with reſpect to its center;

center; but if the ſphere be cauſed to revolve on its own axis, the centrifugal force thence ariſing will diminiſh the gravity of all its parts, except thoſe which are ſituated in the axis of rotation. This diminution will be greateſt in the equator, becauſe of the increaſed velocity, and becauſe the centrifugal force acts directly againſt the force of gravity. And the nearer the parallel of latitude or circle of rotation is to the pole, the leſs will the gravity of the parts be affected, both the above mentioned cauſes being leſs. Whence the equilibrium, which before ſubſiſted between the columns in a ſpherical figure, will be deſtroyed, and the ſame effect muſt take place, as would follow if the columns at the equator were ſhortened; that is, the columns towards the poles will ſubſide, and thoſe at the equator be elevated, till the difference of their lengths compenſates for the difference of their gravities. Thus the ſphere, by its rotation, will be changed into a ſolid, whoſe radii are longeſt near the equator, and ſhorteſt towards the poles, the axis being the ſhorteſt of all its diameters.

By a computation grounded on theſe and other conſiderations, it is ſhewn, that bodies

at

at the equator of the Earth loſe more than $\frac{1}{289}$ part of their gravity, and that the equatorial diameter is to the axis as 230 to 229, upon the ſuppoſition that the Earth is every where of the ſame uniform denſity. For what has been ſaid of a fluid maſs will hold good of the Earth, ſince if it were not of this figure, but ſpherical, the ocean would overflow the regions near the equator, and leave the polar regions elevated many miles above the level of the ſea. But experience ſhews, that the land is in general no more elevated above the ſea in one part of the globe than another.

This decreaſe of gravity near the equator is remarkably ſeen in the motion of pendulums. For a pendulum, which in a higher latitude vibrates ſeconds, is found to go ſlower at the equator, and that in a much greater proportion than can ariſe from the lengthening of the rod by heat, nay, even in the coldeſt parts of the mountains of Spaniſh America, which are conſtantly covered with ſnow. From the juſt mentioned quantity of diminution of gravity, it is not difficult to compute the length of a pendulum which ſhall vibrate ſeconds in a given

given latitude, and from the agreement of theſe computations with experience, the oblate ſpheroidal figure of the Earth, as alſo the diurnal rotation from which it originates, are both confirmed.

The ſame concluſion has likewiſe been obtained from the labours of many ingenious and learned men, who have actually meaſured the length of a degree of the meridian in different latitudes, by which it appears that the degrees are ſhorter towards the poles than near the equator. And as the radius muſt conſequently be ſhorter, the polar regions are nearer the center, or in other words, the Earth is flatted at the poles.

Theſe menſurations conſtitute the experimental proof of the Earth's rotation on its axis; for it is evident that a centrifugal force cannot be produced but by an abſolute motion: and as the effects of this force are obſerved in the figure of the Earth, and not at all in the heavens, the motion of the Earth muſt be abſolute and real, and that of the heavens only relative and apparent.

The planet Jupiter revolves on its axis in leſs than ten hours; a rapidity which much

exceeds

exceeds that of the Earth; and his figure differs accordingly much more from that of a ſphere, his equatorial diameter exceeding his polar diameter, according to the obſervations of aſtronomers, as 13 to 12.

If a number of fluid bodies revolved about the Earth at equal diſtances from its center, they would, by the action of the Sun or any other planet be ſubject to the ſame irregularities as the Moon; that is, they would approach nearer, and move ſwifter at the conjunction and oppoſition than at the quadratures. And if this number were ſo great as to become contiguous, and form a fluid ring or circle, the parts of this ring would be affected in the ſame manner. If it were inclined to the ecliptic, the nodes would be ſtationary when in the conjunction and oppoſition, and be carried in a retrograde direction in the other revolutions, but moſt ſwiftly when they were ſituated in the quadratures. Its inclination would likewiſe vary in every revolution, and in a period ſomewhat leſs than a periodical year would be diminiſhed and increaſed, by turns, twice.

Suppoſe

Suppoſe this fluid ring to be of the ſame diameter as the Earth, to be placed in a cavity hollowed round the Earth at the equator, and to revolve in the ſame time and direction as the Earth does on its axis. It would then move, at the conjunction and oppoſition, ſwifter than the ſurface of the Earth, and ſlower at the quadratures; and conſequently, with reſpect to the ſurface of the Earth, would ebb and flow like a ſea. For, by reaſon of the increaſed ſwiftneſs at the conjunction and oppoſition, and the retardation at the quadratures, the fluid, between the conjunction or oppoſition and the enſuing quadrature, would form a cumulus or heap, while a correſpondent defect would happen in the other quadrants which precede the conjunction and oppoſition.

If this ring be now ſuppoſed to be frozen or converted into a ſolid, the flux and reflux will ceaſe, but the preceſſion of the nodes and the libratory increaſe and decreaſe of the inclination will remain. Suppoſe the ring to adhere to the ſurface of the Earth at the equator, inſtead of being admitted into a cavity; it will then communicate part of its

motion

motion to the Earth, the nodes of whose equator will recede, but with a much slower motion than those of the ring would have receded, if it had not adhered to the Earth, and the obliquity or angle which the equator makes with the ecliptic, will be diminished and increased alternately twice in a year. The elevation of the equatorial parts have the same effect as such a ring would have; for the excess of matter in those regions supplies its place.

Astronomers begin the year in the Spring, when the Sun is in that node of the equator, or equinoctial point at which the days begin to lengthen in the northern hemisphere. Now it is plain, that if the equinoctial points had no motion, the Earth would complete one revolution in her orbit in the same time that the Sun employs in apparently passing from one of the equinoxes, and returning again to the same. But, because of the retrograde motion, the line of the nodes of the equator, or diameter of the Earth which joins the equinoctial points, is brought to coincide again with the line which joins the centers of the Sun and Earth, before her periodical revolution

revolution is completed; and therefore the circle of the ſeaſons is performed in leſs time than the Earth's revolution in her orbit. The actions both of the Sun and Moon on the redundant matter in the equatorial regions tend to produce this motion, which is ſo ſlow, that a complete revolution will not be finiſhed in leſs than twenty-five thouſand years. This is called the preceſſion of the equinoxes, and is the reaſon that the fixed ſtars appear to advance in longitude about 50 ſeconds of motion in a year; whence it has happened, that ſince the time of Ptolemy, the zodiacal figures have advanced the greateſt part of a whole ſign: the conſtellation Aries being ſituate in that part of the ecliptic which is denominated from Taurus, Taurus in the place of Gemini, &c. The difference between the natural year or period of the ſeaſons, and the periodical year, or time of the Earth's revolution in her orbit, is 20^{m} 17^{s}; for the natural year conſiſts of 365^{d} 5^{h} $48'$ $57''$; and the periodical year of 365^{d} 6^{h} $9'$ $14''$.

The libratory variation of the inclination of the equator to the ecliptic is termed the

nutation of the poles; and is much too ſmall to be ſenſible by any of the preſent methods of obſervation.

CHAP. IV.

Of the Tides.

THOUGH the cauſe of the tides may be collected from what was ſaid in the laſt chapter; yet, as it is the only vulgar inſtance we have of the mutual gravitation of the cœleſtial bodies, and was the Nodus Philoſophorum before Sir Iſaac Newton, it may not be amiſs to give a more particular explanation of it.

If the Earth were every where covered with a deep ſea, it is plain, from the reaſons before recited, that the water would not, in the diurnal rotation, move with the ſame uniform velocity as the Earth. For, if the apparent diurnal revolution of the Moon be called a lunar day, and be divided into twenty-four equal parts or hours, the water which is ſituated on the meridian over which the Moon

Moon at any time is, will move ſwifter, and the water which is ſituated in the meridian ſix hours to the eaſtward or weſtward, will move ſlower: ſince the water on each parallel of latitude may be conceived to be a fluid ring, and will be affected by the diſturbing force nearly in proportion to its diameter. The ſea, then, being accelerated at the meridian upon which the Moon is, and retarded at the meridian, which is 90° or 6 hours to the eaſtward, will be accumulated between the two places; its greateſt height being at the half diſtance, or meridian which the Moon has paſſed three hours. And on the other hand, the retardation at the quadrature to the weſtward, preventing the water from flowing as faſt as the acceleration at the meridian, at which the Moon is, carries it away, the ſea muſt of courſe be depreſſed between the two places, its greateſt depreſſion being at the half diſtance, or meridian at which the Moon will arrive in three hours. A ſimilar accumulation and diminution will happen at the places which are diametrically oppoſite to thoſe here deſcribed, though not altogether ſo great. The diſturbing force of the Sun will act in a like

manner, but lefs ftrongly; for though the Moon's attractive force be vaftly lefs than that of the Sun; yet, becaufe her diftance in comparifon to that of the Sun from the Earth is very fmall, the forces with which fhe acts on different parts of the Earth will vary more confiderably from parallelifm and equality; and the irregularities in any fyftem, which arife from the actions of forces from without, are occafioned, not by the whole actions of the forces, but only by their differences in quantity, or want of parallelifm in direction.

Thus, it is evident, that the fea, as far as circumftances allow, muft in every place be raifed to its greateft and leaft height, alternately twice in each lunar day. Being elevated once at three lunar hours after the Moon has paffed the meridian of the place, and once at twelve hours after, or three hours after the Moon has paffed the oppofite part of the fame meridian; and at fix hours after each of thefe elevations its greateft depreffions follow. This appears by the tides in the Atlantic ocean on the weftern coafts of Europe and Africa, and in the Pacific ocean on the open coafts of Afia and America, where high-water always

always happens about the third hour after the Moon has paſſed the meridian, except where the motion of the ſea is ſomewhat impeded by flats or ſhoals.

The effects of the diſturbing forces of the Sun and Moon are not ſeen diſtinctly, but compounding with each other produce a motion which is different from what would have ariſen from the ſingle action of either luminary. At the time of the conjunction or oppoſition their effects are united, and the tides are greateſt, being what are called Spring-tides. When the Moon is in the quadrature, the Sun's action raiſes the water where the action of the Moon depreſſes it, and depreſſes it where the action of the Moon raiſes it: from the difference of their actions therefore ariſes the leaſt, or, as they are called, Neap-tides. And, becauſe the action of the Moon exceeds that of the Sun, high-water follows the third lunar hour. At other times high-water ariſing from the lunar force would happen on the third lunar hour, and that which ariſes from the Sun's force on the third ſolar hour; but the forces being compounded, produce a tide which happens at ſome intermedi-

ate time, but which, on account of the greater force, is neareſt to the third lunar hour. Conſequently, when the third ſolar hour precedes the third lunar hour, as is the caſe while the Moon is in the firſt and third quarters, high-water happens ſooner than the third lunar hour, and the contrary happens when the third lunar hour precedes the third ſolar hour, as in the ſecond and fourth quarters. It is to be noted, that we have not here made any diſtinction between the hour of the Sun or Moon's paſſing the meridian above the horizon, or beneath it; the effect being nearly the ſame with reſpect to the tides.

The effects of the diſturbing forces of the Sun and Moon depend likewiſe upon their reſpective diſtances from the Earth. For theſe effects are greater at leſs diſtances. And therefore in winter, when the Earth is in her perihelium, the Sun being nearer, cauſes the ſpring-tides to be ſomewhat greater and the neap-tides ſomewhat leſs, than in the ſummer; and the Moon being each month in her perigeum, does then, in like circumſtances, cauſe greater tides than at other times; whence it happens, that if a great ſpring-

ſpring-tide happens when the Moon is in her perigeum, the next ſpring-tide will be leſs, becauſe the Moon will be then in her apogeum, or greateſt diſtance.

The tides vary likewiſe in conſequence of the varying declinations of the Sun and Moon. For if either of theſe luminaries were ſuppoſed to be at the pole, it would neither accelerate nor retard the diurnal rotation of the water, but would occaſion a conſtant elevation at the poles, by diminiſhing the effect of gravity there, and a conſtant depreſſion at the equator. Therefore, no alternate riſe and fall of the water or tide would be produced. Conſequently, as the Sun and Moon decline towards the pole, they gradually loſe their effects, and the tides become leſs conſiderable. When the Sun is in the equator, and the Moon at the tropic, or her greateſt declination, the tides are leſs than when the Moon is at the equator, and the Sun in the tropic: becauſe in the firſt caſe the Sun's influence is the greateſt poſſible, and the Moon's leaſt; and in the latter the Moon's influence is the greateſt poſſible, and the Sun's leaſt: and as the tides depend more

upon the Moon's influence than that of the Sun, they are greateſt when her action is greateſt. When the Sun and Moon are both in the equator, the ſpring-tides are the greateſt of any. However, becauſe the Earth is nearer the Sun in winter than in ſummer, the greateſt autumnal ſpring-tides are generally later than the equinox; and the greateſt vernal ſpring-tides are generally before the equinox.

When the Moon declines either to the northward or ſouthward of the equator, one of the greateſt elevations of the water follows the Moon, and deſcribes nearly the ſame parallel of latitude as the Moon, by the diurnal motion, apparently deſcribes; and the other greateſt elevation being diametrically oppoſite, muſt, of courſe, deſcribe a parallel of latitude at an equal diſtance on the other ſide of the equator. The greateſt elevation, which moves on the ſame ſide of the equator with a given place, will come nearer to it than the oppoſite elevation; and therefore when the Moon declines towards the ſame ſide of the equator, as that on which the given place is ſituated, the day-tides, or tides

tides which happen while the Moon is above the horizon, will be greateſt, and the night-tides, or thoſe which happen while ſhe is beneath the horizon, will be leaſt. And the contrary happens when the Moon declines to the other ſide of the equator. Thus, the elevation at high-water is alternately greater and leſs; and the difference is greateſt when the Sun and Moon both deſcribe the ſame tropic, becauſe the oppoſite elevations then deſcribe the tropics, which are the fartheſt from each other of any two parallel circles they can poſſibly deſcribe. This difference is found to be about a foot at Plymouth, and fifteen inches at Briſtol.

If the actions of the Sun and Moon were to ceaſe at once, the tides would not immediately ceaſe, but would continue for ſome time by the undulating motion of the water. This undulation would be greater, if the actions were to ceaſe at the time of a great tide than at the time of a leſs; and therefore leſs tides, which ſucceed greater, are more increaſed by it than greater tides which ſucceed leſs: conſequently the difference between the tides is rendered leſs than it would other-

wiſe

wiſe have been, and the greateſt ſpring and neap-tides do not happen preciſely at the conjunction or oppoſition and quadratures, but two or three tides later.

If the greateſt acceleration and retardation of the diurnal motion cannot ſubſiſt in the ſame ſea at the ſame time, the accumulation or defect muſt conſequently be leſs; that is to ſay, if one of the ſhores or coaſts of any ſea be leſs than ninety degrees to the eaſtward or weſtward of the other, and the eaſtern coaſt, for inſtance, be immediately under the Moon, the acceleration will, by cauſing the water to riſe, occaſion a defect or fall to the weſtward, becauſe the weſtern parts, being retarded, do not follow with a velocity ſufficient to ſupply what is carried to the eaſtward by the acceleration: and the greater this retardation the greater the defect or fall. But ſince by the ſuppoſition the weſtern ſhore is not ninety degrees diſtant, the retardation is not there ſo great as it would have been had the ſea been wider; and therefore the fall is not ſo great. By a like argument it appears, that when the Moon is at the meridian of the weſtern coaſt the elevation is leſs,

if

if the ſea be leſs than ninety degrees from eaſt to weſt. Hence in ſmall inland ſeas the tides are inconſiderable; and for this cauſe, in the Atlantic ocean the tides do not riſe ſo high between the tropics as they do farther to the north or ſouth, the ſea being narrower between America and Africa in the lower, than in the higher latitudes. From hence alſo follows the reaſon why the tides are ſo ſmall as they are found to be at the iſlands of St. Helena and Aſcenſion, which lie in the middle of that ſea; for, ſince the water cannot riſe on the one ſhore but by falling at the other, it muſt continue at a mean height at theſe intermediate diſtant iſlands.

This theory of the tides is perfectly conſentaneous to experience in the open and deep oceans; and in the leſſer ſeas, as has been obſerved, the tides are very ſmall. But, when thoſe leſſer ſeas have a free communication with the ocean, the tide flows into them in a kind of wave, which on its arrival at any place cauſes high-water. Thus it is high-water in the ocean to the weſtward of England and Ireland at the third lunar hour; after which it begins to ſubſide. This ſubſidence

muſt,

must, of course, raise the water round about, whence a flood begins to enter the English channel at about the sixth hour; its course being retarded by the shallowness of the water. Another flood enters the German sea to the northward, near the Orkney islands, and proceeds to the southward. As these floods proceed on their respective courses, it is high-water successively at every place on the coasts at which they arrive, and when the wave has passed any place the water begins there to subside. For example; it is high-water at Plymouth about the sixth hour, at the Isle of Wight about the ninth hour, and at London-bridge about the fifteenth hour after the Moon has passed the meridian, and caused the tide in question. Therefore, when it is high-water at Plymouth the water out at sea has half subsided; when it is high-water at the Isle of Wight it is low-water out at sea; and when it is high-water at London-bridge it is low-water at the Isle of Wight, and a second flood or elevation has already come to its height out at sea.

There are situations where the tide may be carried to the same port by different pas-

sages

ſages or channels, and may paſs quicker through one paſſage than another: in which caſe, the ſame tide, arriving at different times through the different paſſages, muſt occaſion a variety of phenomena. Suppoſe two equal tides to arrive at the ſame port from different places; the one at the third, and the other at the ninth hour after the Moon has paſſed the meridian; the firſt tide therefore preceding the latter by ſix hours; and ſuppoſe the Moon to be at the equator: then, every ſix hours a tide will arrive, which, flowing in at the ſame time as the preceding equal tide ebbs out, will cauſe the water to continue at the ſame height, and thus it will neither riſe nor fall during the whole day. But, if the Moon decline from the equator, the tides in the ocean will be alternately greater and leſs, as has been obſerved; and therefore there will arrive at this port, alternately, two greater floods proceeding from the greater tide in the ocean, and two leſſer floods proceeding from the leſſer tide in the ocean. At the mean or intermediate time between the

the arrivals of the two greater tides; the water will then be higheſt; between a greater and a leſſer tide it will be at a mean height; and loweſt of all at the middle time between the arrivals of the two leſſer tides. By theſe means, in the ſpace of twenty-four hours, the ſea will riſe to its greateſt, and fall to its leaſt height but once, inſtead of twice, as in general it does in other places; and if the Moon decline towards the ſame ſide of the equator, as that on which the port is ſituated, the two greater tides will arrive at the third and ninth hours, and the greateſt elevation will be at the ſixth hour, or at about the ſetting of the Moon: the leaſt elevation will conſequently happen between the two leaſt tides, at the eighteenth hour, or about the riſing of the Moon. And the ſame effects will take place when the Moon declines to the contrary ſide of the equator; but with this difference, that whereas high and low water happened then reſpectively at the ſetting and riſing of the Moon, they will in the preſent caſe happen reſpectively at the riſing and ſetting of the Moon.

A remarkable inſtance of all theſe particulars is adduced by Dr. Halley, in the port of Batſha, in the kingdom of Tonquin, which lies in 20° 50′ north latitude. There, on the day on which the Moon paſſes the equator, the water ſtagnates; afterwards, on the Moon's declining to the northward, it begins to ebb and flow; not twice in the day, as in other ports, but once only; and high-water happens at the ſetting, and low-water at the riſing of the Moon. The tides increaſe with the Moon's declination for ſeven or eight days; after which, for the next ſeven days, they decreaſe by the ſame gradation as they before increaſed, till the Moon's arrival again at the equator, when they ceaſe, and upon her changing her declination are reverſed. For while her declination becomes ſoutherly, low-water happens at the ſetting, and high-water at the riſing of the Moon; which continues till her declination again changes. Now it appears, that the tide muſt come to this port by two inlets or paſſages; one between the continent of China and the iſland Luconia,

nia, communicating with the Chineſe ocean, and the other between the iſland of Borneo and the continent. But whether the tide arriving from the Indian ocean after a courſe of twelve hours, and from the Chineſe ocean after a courſe of ſix, and thence happening on the third and ninth lunar hours be the cauſe of theſe appearances; or whether ſome other circumſtances may not be concerned in producing the effect, muſt be determined by future obſervations on the neighbouring coaſts.

BOOK

BOOK II.

SECT. I.

Of Light and Colours.

CHAP. I.

Of the limited State of the human Faculties.

IN the former part of this treatife, our attention was chiefly engaged by thofe phenomena which arife from the motions and mutual actions of bodies whofe magnitudes are confiderable enough to become the objects of fenfe. But the motions by which the operations of nature are performed, are not, for the moft part, within the reach of our faculties; either by reafon of the minutenefs of the fyftem of moving and mutually acting bodies, or the celerities of their motions.

Our ſenſes are bounded on either hand, by an immenſity, of which an exceedingly ſmall part comes under their perception. We reaſon concerning motion and attraction, but can form no conception of either: we judge from effects only; their cauſes are, and probably will for ever be, myſterious. The laws of motion, for inſtance, are founded on no reaſoning: in vain the metaphyſician attempts to demonſtrate, that a body will preſerve its ſtate of uniform motion or reſt; it is experience alone that has afforded the proof. Reaſon is founded in the compariſon of ideas; and when we are arrived at the fountain head of our knowledge, when we have brought our principles to the utmoſt poſſible degree of ſimplicity, the ſearch is at an end: want of materials prevents all further progreſs.

Thus the bounded ſtate of our faculties by which thoſe materials are acquired, is an inſurmountable bar to the perfection of our knowledge. In things or acts of the ſame nature reaſon, by the method of analogy, is able to carry us far beyond the immediate ſphere of our ſenſes: but when the object is of a different nature from any foregone

gone perception, it may frequently be ſuch as intirely to elude them, and of courſe, never to come under the notice of the reaſoning faculty. It is impoſſible for a blind man to form any idea of the manner in which we who ſee are affected by colours; for though an inſtance is recent of a * teacher of optics, who never was endued with ſight, yet his knowledge was merely that of the mathematical part, which may be obtained from the abſtracted conſideration of lines and angles. It is therefore not only poſſible, but very probable, that there may be many agents in nature which eſcape our obſervation merely for want of additional ſenſes. If the ſenſation of the olfactory nerves were as obtuſe as that of thoſe nerves which, being diſtributed over the ſurface of the body, are ſuppoſed to be the organs of feeling, it is evident that we ſhould not ſo much as ſuſpect that ſuch potent and plentiful emanations were conſtantly flowing from odoriferous bodies; for they are too minute to affect the touch, and too tranſparent to affect the ſight. Serpents

* The learned Sanderſon.

are ſaid to be ſtupified with the ſmell of muſk. Granting the fact, how many ingenious hypotheſes of ſympathy or antipathy would have been invented for the ſolution of the appearance by the philoſophers of the Carteſian ſchool, if they had not been endued with the ſenſe of ſmelling. Thus, again, the current of the air which we call wind, is perceptible enough to the touch; but thoſe extremely quick undulations which give us the ſenſation of ſound would have for ever remained undiſcovered, if the Creator had omitted to provide us with the curious apparatus which is adapted for that purpoſe in the ear. Without that moſt perfect optical inſtrument, the eye, we ſhould have remained totally ignorant of that very principal agent light, except ſo far as it produces heat; and ſhould have found as much difficulty, then, in conceiving how the knowledge of the exiſtence of diſtant bodies could be obtained without contact, as we now do in conceiving how diſtant bodies can mutually act on each other by attraction or otherwiſe. Another ſenſe would probably clear up many of our difficulties, by expoſing the intermediate

agents;

agents; but as the caſe now is, it becomes us to be wary, and direct our ſearch to thoſe objects, in the contemplation of which, there is ſome proſpect of ſucceſs. It ariſes from a narrow and contracted way of thinking, that we are ſo ready to ſuppoſe the human faculties equal to every attempt; and much time and labour would be ſaved, if a due conſideration were conſtantly had of what is and what is not in our reach. Yet, however certain we may be of the imbecility of our powers, and however probable it may be, that the greateſt part of nature is hid behind an impenetrable veil, it is highly neceſſary to advance as far as the lights of which we are in poſſeſſion will allow. Such a proceeding, beſides the numberleſs advantages which ariſe in common life from the ſciences, is ſo natural to the conſtitution and texture of the mind, that it may juſtly be doubted whether we are capable of ſtanding ſtill with reſpect to increaſe of knowledge. If the attention be not directed to affairs of conſequence, it will of itſelf fix upon trifles.

Of the many intelligences we receive from our ſenſes, there ſtill remains a great number

which have not been accurately or rightly confidered. Before the time of Sir Ifaac Newton, it was never fufpected that the rays of light confifted of a mixture of particles poffeffed of the property of exciting ideas of an almoft infinite number of colours: and till this laft century, the electric matter, which is perhaps one of the principal agents in nature, was intirely unnoticed; the means of fubjecting it to the obfervation of our fenfes being till then unknown. Original difcoveries in nature have ufually arifen from accidental circumftances; for where there is no ground for previous argumentation, it is clear that a fettled intention can feldom be followed. Nothing feems more furprifing and extranatural than the electric fhock. The laws by which that fluid, if it may be fo called, acts, are yet very imperfectly known, and it is not impoffible but that future operators may meet with phenomena as unexpected and as ftrange as that uncommon fenfation was to the philofopher who firft experienced it.

We have already confidered the laws of motion, and applied them to the mechanical

construction of the solar system. We now descend to Earth, and it appears natural to apply our attention to the objects of those two senses which are most concerned or engaged with the actions of things placed at a distance, namely, the sight and the hearing. We shall, therefore, in the first place, proceed to treat of light.

CHAP. II.

Of the Properties of Light in general.

IT is generally agreed, that light consists of parts or particles of an extreme minuteness, which are projected in every direction from the luminous or radiant body. This definition however agrees with the phenomena which have hitherto been observed, which are so many and various, that there can be little doubt of its truth.

It is needless to enumerate the various opinions which have been entertained concerning light, when natural philosophy was not so well understood as at present. The

only hypothesis retained by any of the moderns which differs from the above definition, is that which supposes light to consist in certain undulations of an etherial fluid, in the same manner as sound is produced in the gross air. The great facility with which an active imagination may draw parallels between light and sound, has deceived even philosophers of merit and eminence. In order to overthrow this supposition, it may be observed, that the existence of the etherial fluid which is called in to solve the phenomena of light, has never been proved; and again, that the action of an undulating fluid must necessarily produce appearances exceedingly different from those of light.

Though the business of an introductory book be rather to explain the truth in a direct manner, than to enumerate and confute the errors of others; yet a respect for the name of the learned *Euler*, which stands first among the supporters of this doctrine, may plead an excuse for an attention to it, which otherwise might with justice be thought unnecessary.

Undulations can be excited only in the internal parts of fluids which are elastic, or at the

the surfaces of non-elastic fluids which have a tendency to regain their first situation. The first kind of undulation consists of alternate condensations and rarefactions, and the latter of alternate elevations and depressions. These alternations are in both cases termed waves, but as the latter kind is more immediately subjected to common observation, it will be convenient to explain from thence as much as our present purpose requires without entering into the elements of these motions.

Let A (fig. 52.) represent a point of the surface of stagnant water, near which a solid body is suddenly immersed. The water must give way to admit it; and as it is easier to overcome the gravity of a small quantity of the water, than to give motion to the whole, a small quantity will rise on every side, and form a circular wave, of which bb may represent a part; this wave subsiding, will generate another, cc, which will produce another, dd, and so on. Let DE represent an obstacle, perforated at F; the waves will pass through, and proceed to I, K, L, M, &c. But it is

ob-

obvious, both from reason and experiment, that instead of being confined between the lines BA and CA, they will every where spread into the confines towards N and O, as in the figure. And if bb, cc, dd, &c. represent the pulses or waves of an elastic medium, it is equally clear that they will diverge every way, after passing the perforation F. Thus, we find that sound, which is caused by the pulses of the air, does not proceed in right lines, but is heard through any perforation, however sinuous or winding: and light ought to be perceived in the same manner, if it were caused by the undulations of a medium: but as experience evidently contradicts this, the supposition must therefore be false.

It is no argument to reply, that the supposed etherial fluid may be of such a constitution, as that its pulses shall not deflect laterally; for, not to mention that such deflection is a natural consequence of elasticity, it is obvious that the rational method of enquiry in natural philosophy is at an end, if, to suit our present occasion, we may be allowed to feign subtile fluids endued

with

with properties unlike any thing in nature. If this liberty be allowed, the hypotheſis, when diveſted of its parade of ſimilies and alluſions, amounts to no more, than that light is cauſed by the action of a fluid which is capable of cauſing it; or, in fewer words, that light is light.

We have already had occaſion to obſerve the aſtoniſhing minuteneſs of the particles of light; and in treating on the ſatellites of Jupiter, mention was made of the degree of its ſwiftneſs. From that degree of ſwiftneſs may be deduced another argument to prove how ſmall the particles muſt be. For it is found, that a ball from a cannon at its firſt diſcharge flies about a mile in * eight ſeconds, and would therefore arrive at the Sun in about 32 years, ſuppoſing it to move with unremitted velocity. And light, as was before obſerved, moves through that ſpace in about 8 minutes, which is two million times as faſt. But the force with which bodies move, are as their bulks multiplied by their velocities; and conſequently if the particles of

* This varies according to the charge of powder and other circumſtances.

light

light were equal in bulk to the two millioneth part of a grain of ſand, we ſhould be no more able to endure their impulſe, than that of ſand ſhot point blank from the mouth of a cannon.

The rarity of light is not leſs a matter of wonder than its velocity and the minuteneſs of its particles. For its rays croſs each other in all directions without the leaſt apparent diſturbance. We can eaſily ſee through a ſmall hole, not exceeding the $\frac{1}{100}$ part of an inch, the objects, as the ſky, trees, houſes, &c. which occupy almoſt an entire hemiſphere. The light proceeding from all theſe objects muſt therefore paſs at the ſame inſtant through the hole in a very great variety of directions before they arrive at the eye; yet it does not appear that viſion is in the leaſt diſturbed by that means.

The ſpace through which light paſſes is called a medium; by which term reference is had to the quantity or denſity of the matter contained in the ſpace: thus glaſs and air are mediums, but a vacuum, or ſpace abſolutely void, is a medium alſo.

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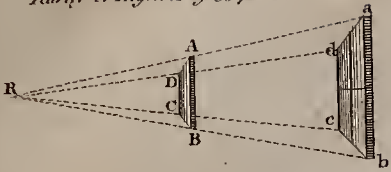
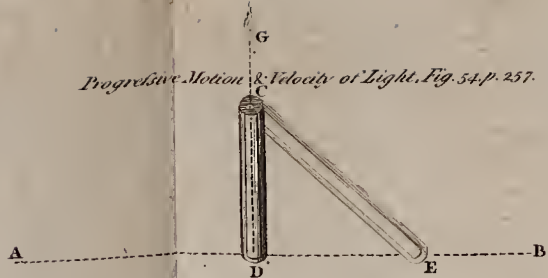
No. XIII.

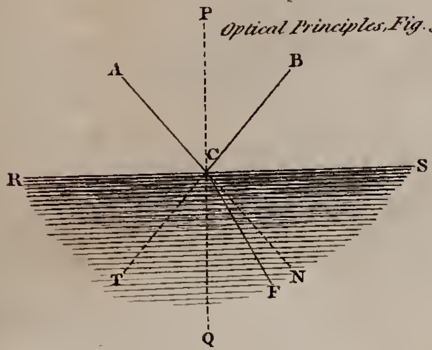
Rarity of Light. Fig. 53. p. 253.



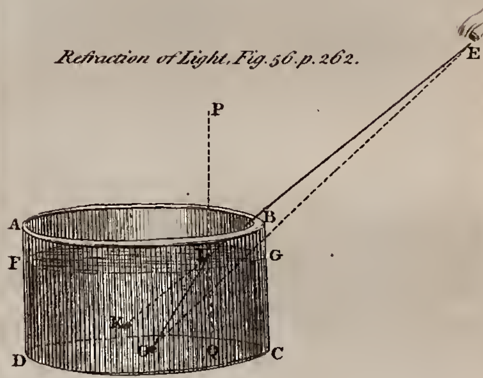
Progressive Motion & Velocity of Light. Fig. 54. p. 257.



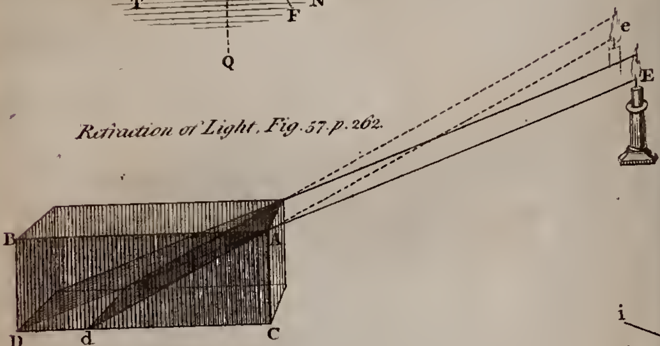
Optical Principles, Fig. 55. p. 260.



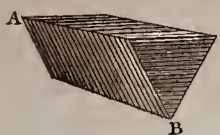
Refraction of Light. Fig. 56. p. 262.



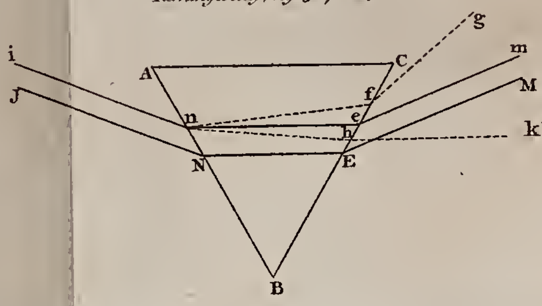
Refraction of Light. Fig. 57. p. 262.



Refrangibility, Fig. 58. p. 264.



Refrangibility, Fig. 58. p. 264.



When light paſſes through mediums, either abſolutely void or containing matter of an uniform denſity and of the ſame kind, it always is found to proceed in ſtraight lines. Whence it follows, that the rarity of light increaſes as the ſquare of the diſtance from the radiant body. For the light which falls on the ſquare ABCD, (fig. 53.) from the point R, at the diſtance RA, will be ſpread over a ſurface, abcd, four times as large at twice the diſtance, or Ra.

From this principle we may compare the denſities of light at different diſtances from the Sun, or any other luminous body; and it may not be improper in this place, to compute the difference between the denſity of the light of a fixed ſtar, and that of the Sun at the planet Mercury, and alſo at the comet of 1680, that we may from thence make a rough eſtimate of the magnitude of its particles.

By the moſt accurate obſervations it appears, that the annual parallax of the neareſt fixed ſtar does not amount to one ſecond. The diſtance of ſuch ſtar cannot therefore be leſs than 34,000,000,000,000 miles; and conclud-

ing, by the reaſoning at page 184, the ſtar to be a Sun like that which illuminates our ſyſtem, it follows that the light of the Sun at an equal diſtance would be nearly the ſame as that of the ſtar. The diſtance of Mercury from the Sun in round numbers is 31,670,000 miles, which being ſquared, is equal to the $\frac{1}{1,000,000,000,000}$ part of the ſquare of the ſtar's diſtance: therefore the Sun's light at Mercury is ſo many times denſer than that of the ſtar. But the comet of 1680 deſcended to a region in which the light was 4,000 more denſe than at Mercury; its diſtance being but $\frac{1}{6}$ of the Sun's diameter from his ſurface. Conſequently the light at the comet, when in perihelio was 4,000,000,000,000,000 times more denſe than that which we receive from a fixed ſtar. Let it be ſuppoſed, that the light at the comet was ſo denſe as that its particles were nearly contiguous, and that the light of a fixed ſtar is ſo rare, that when viewed through a hole of the $\frac{1}{100}$ part of an inch diameter, no more than 10 particles paſs to the eye at a time: then, 4,000,000,000,000,000, multiplied by 10, will ſhew the number of particles which may paſs through the ſame hole at a time

time when nearly contiguous. That is, to ſay, 40,000,000,000,000,000 particles of light may be contained or circumſcribed within a circle of $\frac{1}{100}$ of an inch in diameter, or $\frac{1}{10000}$ of a ſquare inch in ſurface. But ſuch a circle would not contain above one grain of ſand; and therefore it follows, that a particle of light covers a ſurface much leſs than the $\frac{1}{40,000,000,000,000,000}$ part of that which is covered by a grain of ſand. Now, if there be two ſpheres, the ſurfaces of whoſe generating or principal circles are as 40,000,000,000,000,000 to 1, their bulks or ſolid contents will be nearly as 134 (64 cyphers) to 1 in round numbers. Whence it follows, that the bulk of a particle of light is not equal to the $\frac{1}{134\ (64\ \text{cyphers})}$ part of a grain of ſand. But this computation makes the particles of light incomparably too large; for the ſuppoſition that its particles are nearly contiguous cannot be allowed except at the ſurface of the Sun.

Another proof of the extreme ſmallneſs of the particles of light is, that the leaſt viſible ray may be made to paſs through ſpaces, in which other light is very much condenſed,

without

without ſuffering any deflection or diminution from the action of ſuch condenſed light.

The velocity of light was firſt determined by Monſ. Romer, from obſervations on Jupiter's Moons, which have ſince been confirmed, and generally received. The ſagacious Mr. J. Bradley, by obſervations made on the ſtar γ in the conſtellation Draco, with inſtruments of ſurpriſing accuracy, for the purpoſe of determining its parallax, has likewiſe determined the progreſſion and velocity of light; which appears to be the ſame as that deduced from the ſatellites of Jupiter. And thus the motion of the Earth is proved, as well from obſervation, as it before was from reaſon and the nature of things. We ſhall here give a ſhort explanation of the principle on which this diſcovery is founded, the original account of which is to be found in the Philoſophical Tranſactions for the year 1728, N° 406.

Suppoſe a tube to be erected perpendicular to the horizon, at a time when it rains, the drops falling perpendicularly down, and ſuppoſe the diameter of the tube to be ſuch as to admit but one drop at a time: then it is plain

plain that if a drop of water enter the orifice of the tube, it will fall to the bottom without touching its ſides. But if the tube, without altering its poſition, be moved along in the direction of the horizon, the drop will ſtrike againſt one of its ſides, and will not paſs through while the motion continues, unleſs the tube be alſo inclined towards the part to which its motion is directed.

Thus, if AB (fig. 54.) repreſent the horizon, CD the perpendicular tube, and GD the courſe of a drop of rain: then, if CD be moved towards A, while the drop is falling within the tube, it is evident that the inner ſurface of the tube, which is ſituated towards B, will be carried againſt the drop, and prevent its arriving at the bottom. But if the inclined tube EC be moved, with a ſimilar motion to that of the drop, from E to D, in the time that the drop moves from C to D, the lower orifice of the tube and the drop will be found at D at the ſame inſtant; and the velocity of the drop will be expreſſed by CD, and that of the tube by ED.

The ſame reaſoning holds good, if inſtead of drops of rain we ſuppoſe particles of light, and a teleſcope inſtead of a tube.

For

For to an obſerver, who through the tube CD views the vaſtly diſtant object G, if the motion of light be inſtantaneous, or infinitely ſwift, no finite motion of CD, its portion being unaltered, can prevent its being viſible; ſince, by the ſuppoſition, the light which enters at C will arrive at D before CD can have moved at all. But if light be propagated in time, and the obſerver be carried by a motion ſimilar, as to acceleration, to that of light, the tube muſt be inclined to the ray in an angle, whoſe ſine is to the ſine of CED, or the angle the tube makes with the line of the obſerver's motion, as the velocity of the obſerver is to the velocity of light. For in the triangle DCE, the ſides DE and DC, which expreſs theſe velocities, are as the ſines of their oppoſite angles. Hence if the angle of the inclination of the tube, and the velocity of the obſerver's motion be known, the velocity of light may be determined.

By this theory, which is grounded on a great number of obſervations on ſtars of different magnitudes and ſituations, it appears, that the ſmall apparent motion the fixed ſtars have about their real places, which is called

their Aberration, does arife from the proportion which the velocity of the Earth's motion in her orbit bears to that of light. This proportion is found to be as 10210 to 1: from whence it follows, that light moves or is propagated as far as from the Sun to the Earth in 8′ 12″. And it likewife appears, that the motion of light is uniform, and the fame, whether original, as from the ftars, or reflected, as from the fatellites of Jupiter.

From feveral nice experiments, in which the Sun's rays were thrown, very much condenfed, upon a wire, fufpended fo as to move horizontally, it appears that the momentum of light is fufficiently great to impel bodies with a fenfible velocity.

CHAP. III.

Optical Definitions and Principles.

WHEN a ray of light paſſes out of one medium into another, and is bent out of its courſe at their common ſurface, this bending is called refraction.

When a ray of light proceeds to the common ſurface of two mediums, and inſtead of paſſing from the one into the other, is turned back into the firſt, this turning back is called reflection.

The angle of incidence is the acute angle which the line deſcribed by the ray of light makes with a line drawn perpendicular to the ſurface at the point of incidence.

The angle of reflection or refraction is the acute angle, which the line deſcribed by the ray of light after reflection or refraction makes with the perpendicular to the ſurface at the point of incidence.

Thus, if RS repreſent the common ſurface of two mediums, AC (fig. 55.) a ray of

of light incident at C, and PQ a line interſecting the ſurface at right angles at C; then the angle ACP is the angle of incidence. If it be reflected at C, ſo as to return in the line CB, then the angle PCB is the angle of reflection: and if it be refracted at C, ſo as to proceed in the line CF, the angle QCF is the angle of refraction.

The angles of incidence, reflection, and refraction lie in one and the ſame plane.

The angle of reflection is equal to the angle of incidence.

If the refracted ray be returned directly back to the point of incidence, it ſhall be refracted into the line which was before deſcribed by the incident ray.

The refractive powers of different mediums are nearly as their denſities; that is to ſay, refraction out of the rarer medium into the denſer, is in general made towards the perpendicular, ſo that the angle of refraction is leſs than the angle of incidence.

The ſine of the angle of incidence is either accurately or very nearly in a given ratio to the ſine of the angle of refraction, in all obliquities of the incident ray.

All objects ſeen by reflexion or refraction appear in that place or direction, from whence or in which the rays were laſt reflected or refracted to the eye.

Thus, if the ray AC (fig. 55.) proceed from an object at A to C, and be thence reflected to the eye of a ſpectator at B, the object will be ſeen not at A but at T, in the direction of the reflected ray BC. And if the ray FC proceed from an object at F, and be refracted into the direction CA to the eye of a ſpecta-tor at A, the object will be ſeen not at F but at N, in the direction of the refracted ray AC.

On this account it is that objects are ſeen in mirrors or looking glaſſes, and that objects ſeen under water appear out of their true places. Let ABCD (fig. 56.) repreſent a veſſel containing water, whoſe ſurface is FG, and let O repreſent an object at the bottom. Then, to an eye at E the object O will be ſeen at K, by means of the ray OL, which paſſing from a denſer to a rarer medium, is re-fracted from the perpendicular PQ into the direction LE. Or let ABCD (fig. 57.) repreſent a veſſel ſo placed with reſpect to the candle E, that the ſhadow of the ſide

AC

AC may fall at D. Suppoſe it now filled with water, and the ſhadow will withdraw to d, the ray of light EA, inſtead of proceeding to D, being refracted to d. And there is no doubt but that an eye placed at d would ſee the candle at e in the direction of the refracted ray dA.

The mathematical application of the foregoing principles to the rays of light which paſs through glaſſes, or are reflected from mirrors of various figures, conſtitutes that branch of the ſcience of optics which teaches the conſtruction of inſtruments. The explanation of which we ſhall wave for the preſent, till we have given an account of the various reflexibility, refrangibility, and colours of light.

C H A P. IV.

Of the various Refrangibility of the Rays of Light.

LIGHTS which differ in colour differ alſo in refrangibility, and the contrary.

Let AB (fig. 58.) repreſent a wedge or triangular priſm of glaſs, then the triangle ABC may be conceived to be a ſection of the ſame, tranſverſe or at right angles to its axis. Suppoſe JN to be a ray of light incident at N, and thence refracted to E, on the ſurface CB, where it is again refracted into the direction EM; ſuppoſe in to be another ray parallel to the former, and conſequently incident at n, with the ſame angle. Now, if the ray in be equally diſpoſed to be refracted by the priſm, as the ray JN, theſe angles of refraction will alſo be equal, and in will, when refracted into the directions ne and em, ſtill continue parallel to the ray JN, which is refracted into NE and EM. But if it be more refrangible it will be refracted

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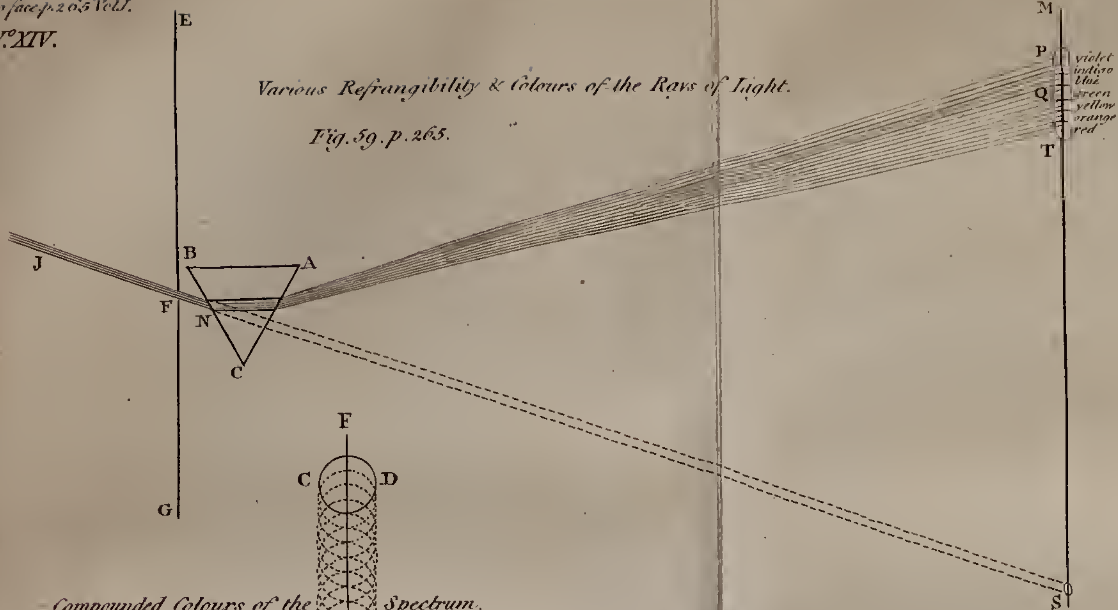
N.º XIV.

Various Refrangibility & Colours of the Rays of Light.

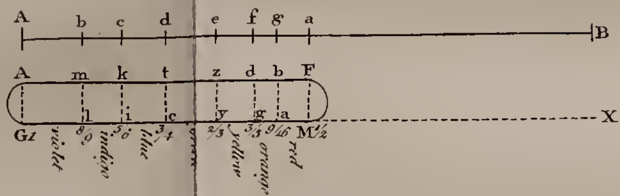
Fig. 59. p. 265.



Compounded Colours of the Spectrum.

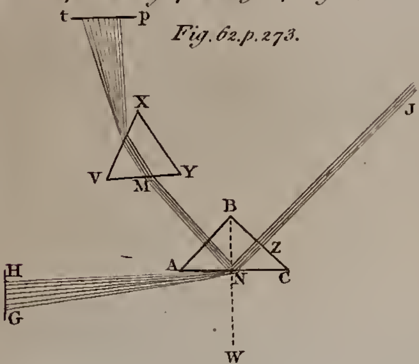
Fig. 61. p. 268.

Harmony of Colours Fig. 60. p. 267.

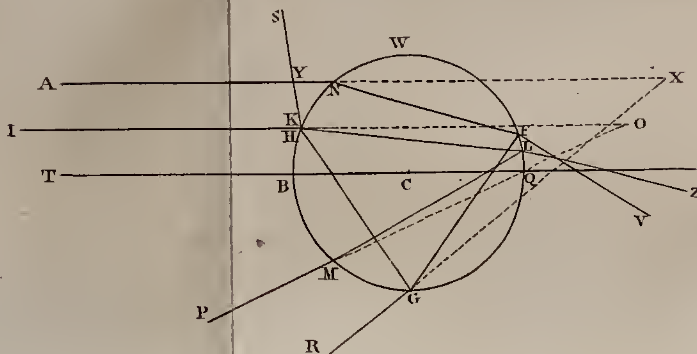


Various Reflexibility of the Rays of Light.

Fig. 62. p. 273.



Theory of the Rainbow, Fig. 63. p. 277.



fracted into directions, as nf and fg, verging more towards the baſe AC, or, if leſs refrangible, it will be refracted into directions, as nh and hk, which verge leſs towards the baſe AC. Whence it appears, that if a pencil or collection of rays fall parallel to each other on one of the ſides of a priſm, and do not proceed parallel to each other on their emergence, it muſt be becauſe ſome of the rays are more refrangible than others.

Let the ſpace contained between EG and MR (fig. 59.) repreſent a darkened chamber, of which thoſe lines repreſent the ſides. Let JN repreſent a pencil of light from the Sun, which paſſing through the hole F, is incident on the ſide BC of the priſm ABC. Now, it is plain, that if the priſm were not interpoſed, the pencil JN would proceed to S, and there illuminate a ſmall circular ſpot on the wall; and from the preceding explanation it is evident, that if all the rays of light were equally refracted by the priſm, the whole pencil, being equally turned out of its courſe, would ſuffer no alteration with reſpect to the paralleliſm of its rays, and conſequently would, after refraction, proceed to Q, and there

there illuminate a ſpot ſimilar to that which would have appeared at S. But if the pencil be compoſed of rays unequally refrangible, the moſt refrangible rays will be thrown farther from S, and the leaſt refrangible, being leſs deflected out of their courſe, muſt fall on a part of the wall nearer to S, while thoſe which are refrangible in the intermediate degrees will fall at interpoſed diſtances between them. The experiment determines, that the Sun's light is compoſed of rays, whoſe refrangibilities are not all the ſame; for after emerging from the priſm, inſtead of illuminating a circular ſpace, they are ſpread into a long ſpectrum, bounded by right-lined ſides and circular ends, and whoſe length is tranſverſe at right angles to the direction of the axis of the priſm.

This oblong ſpectrum is variouſly coloured. The lower part, which conſiſts of the leaſt refrangible rays, is of a lively red, which, higher up by inſenſible gradations, becomes an orange; the orange in like manner is ſucceeded by a yellow; the yellow by a green; the green by a blue; after which follows a deep blue or indigo; and laſtly, a faint violet.

let. With a priſm, whoſe refracting angle was $63\frac{1}{2}$ degrees, ſo placed, that the angle of incidence on the firſt ſurface was equal to the angle of refraction at the emergence or ſecond ſurface, the ſpectrum, received on a wall at the diſtance of $18\frac{1}{2}$ feet, was 10 inches, or $10\frac{1}{8}$ in length. Its breadth is in all caſes equal to that of the circle, which would have been formed by the admitted beam or pencil of light, if the priſm had not been interpoſed.

The ſpaces occupied by the ſeveral colours of the ſpectrum anſwer to the ſubdiviſions of a muſical chord: thus, if AGMF (fig. 60.) repreſent the ſpectrum, and the lines FM, ba, dg, zy, &c. mark the confines of the colours; the ſpace MabF being occupied by the red, agdb by the orange, gyzd by the yellow, and ſo forth, in the order above-mentioned, and GM be prolonged to X, ſo that MX may be equal to GM, the lines GX, lX, iX, eX, yX, gX, aX, MX, will be in proportion to each other as the numbers 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, and therefore expreſs the chords of the key, tone, leſſer third, fourth, fifth, greater ſixth, greater ſeventh, and octave.

octave. Or, to render it more familiar to thoſe whoſe knowledge of muſic is merely practical, let AB repreſent the ſtring of a violin or guittar, and a fret or ſmall bridge be fixed on the finger-board at the middle diſtance a, between A and B; and likewiſe frets at g, f, e, d, c, b, ſo that the diſtances ag, gf, fe, ed, dc, cb, and bA, may be in proportion to the ſpaces occupied reſpectively by the red, orange, yellow, green, blue, indigo, and violet in the ſpectrum; then, if the open ſtring ſound A, the regular accent of the ſtopt notes will be in the minor third from that key; the notes being A, B, C, D, E, F ſharp, G ſharp, and A octave.

Thoſe rays which have the ſame degree of refrangibility will, after refraction, fall within a circle equal to that which would have been illuminated by the light if ſuffered to proceed to S: and therefore the ſpectrum may be conceived to be compoſed of an indefinitely great number of ſuch equal circles, whoſe centers are all on the ſame line. For example; if ABDC (fig. 61.) repreſent the ſpectrum, the circle AB be formed by the red, or leaſt refrangible rays, and the circle

DC

DC by the violet, or moſt refrangible rays, then the rays, whoſe refrangibility is intermediate, will form an innumerable ſeries of circles, and fill up the whole ſpace, ſo that AC and BD will appear as right lines. Now, it is obſervable, that though the light in the ſpectrum being ſeparated into its original rays is much leſs compounded than before, yet it is ſtill compounded in no ſmall degree by the interference of the circles with each other, particularly at the line EF, equidiſtant between AC and BD; and that at the lines AC and BD, where the circles do not interfere at all, the light is perfectly homogeneous or uncompounded. But becauſe the colours in the ſpectrum contiguous on either ſide of any given colour do by mixture compound a colour that differs inſenſibly from the original intermediate colour itſelf, a right line drawn perpendicularly acroſs the ſpectrum will be found in the ſame colour throughout. For moſt experiments in which uncompounded light is required, that of the ſpectrum will be found ſufficiently ſo, but in caſes where a greater nicety is demanded, the diameter of the circles, or breadth of the

ſpeculum may be diminiſhed by methods which it does not ſuit our preſent purpoſe to enlarge upon.

It is evident from what has already been ſaid, that this phenomenon ariſes from the nature of light itſelf, ſome of the rays of which are more refrangible than others. And as an additional confirmation it is obſerved, that if the ſpectrum be received on a board which is perforated, ſo as to let paſs one ray of light, or colour, that ray will not be changed by any refraction it may be afterwards made to ſuffer, but continues the ſame both in colour and refrangibility. And if the colours of the ſpectrum be by reflection or refraction made to unite again, they will again form the compounded colour of whiteneſs.

The quantity of the diſperſion of the rays of light, which at equal diſtances from the priſm is nearly expreſſed by the length of the ſpectrum, does not follow the quantity of the refraction of the mean ray, except in mediums of the ſame kind. Thus, if two priſms of different kinds of glaſs refract the ſolar ray equally out of its firſt direction, the

ſpectrum

ſpectrum of colours formed by the one will be much longer than that formed by the other; and it is found, that in equal angles of mean refraction, glaſs, in the compoſition of which much lead enters, diſperſes the light into its component colours much more than glaſs which abounds with alkaline ſalts.

If by means of two priſms, a ſmall piece of paper be illuminated, the one half with red, and the other half with violet light, and an obſerver view the ſame through another priſm, the paper will, by the different refrangibility of the rays, appear divided into two. For the violet half being ſeen by a more refrangible light, will appear to be carried farther from its true place than the red, and will therefore ſeem to be ſeparated from it. The ſame is likewiſe true of colours which ariſe from the ſeparation of light which is made by bodies on which it falls, and which we are apt to call natural colours; for if a paper be painted, the one half with a lively red, and the other half with an indigo, and it be placed in the Sun's light, it will in like manner appear divided, if viewed through a priſm.

And here it may be neceſſary to obviate ſome miſapprehenſions which might ariſe from the lax and unphiloſophical uſe of terms, which can hardly be avoided without much circumlocution. For inſtance, if we ſuppoſe the hand to be heated by fire, and ſpeak of the hand, the word heat implies the ſenſation, but when we ſpeak of fire, the ſame word is uſed to ſignify quite a different thing, namely, the power which cauſes that ſenſation. This laſt uſe of the term is vulgar and improper; for that which impowers fire to cauſe the ſenſation of heat may be, and moſt probably is, a modification or thing very unlike the ſenſation itſelf, and ought therefore to be diſtinguiſhed from it. In like manner, ſpeaking of coloured bodies, the ſame ambiguity of expreſſion enſues; the colour of a body may be a diſpoſition to reflect one ſort of rays more than another, which diſpoſition may depend upon the ſize and configuration of its particles. Suppoſing this, we receive a ſenſe of that ſize and configuration under the form of colour, which is an idea totally different from the thing which cauſes it,

but is neverthelefs confounded with it by the ufe of the fame term to exprefs both. Therefore, neither the rays of light nor bodies, to fpeak properly, are coloured, but are only poffeffed of fuch modifications as enable them to excite the fenfation of colour in the mind; and confequently when we fpeak of *coloured rays* or *coloured bodies*, the phrafe muft be underftood to be grofs and vulgar, and the fenfe is, rays or bodies endued with power to excite the fenfation of colour.

CHAP. V.

Of the Reflexibility of Light; and of the Rainbow.

THE Sun's light confifts of rays which differ in reflexibility, and thofe rays which are more refrangible are alfo more reflexible than others. Let ABC (fig. 62.) reprefent a prifm, whofe angle B is a right angle, and the two angles A and C equal to each other, and confequently half right

angles. Suppose JN to be a beam of light which passes through the surface BC, and is incident on AC at N. It will then emerge in the direction NG, so that the sine of the angle of refraction GNW may be in a certain ratio to the sine of the angle of incidence BNZ, which in glass is as 3 to 2, nearly. Now when the angle of incidence at N is such, that the sine of the angle of refraction is equal to the radius, the angle of refraction becoming a right angle, the ray cannot emerge, but will be totally reflected or turned back into the glass. This happens in glass when the angle of incidence is about 41 degrees.

That the component rays of light are not all equally disposed to be reflected, is proved by turning the prism slowly on its axis, till the light begins to be reflected; for it then appears that the more refrangible rays are reflected sooner, or at less angles of incidence than those which are less refrangible. Let NM represent the reflected beam, and suppose the prism VXY placed so as to receive and separate it into its component colours by refrac-

refraction: then the light which first begins to be reflected, consisting almost intirely of violet rays, will by the second prism be refracted so as to fall at p, and paint a violet colour. As the first prism continues to be turned on its axis, the light is more and more copiously reflected, and the colours between p and t appear in succession according to their order in refrangibility; violet, indigo, blue, green, yellow, orange, and lastly red, at which time the reflection becomes total: the colours formed by refraction at HG disappearing as those at pt appear.

White light being proved to consist of rays which differ in refrangibility, reflexibility and the power of exciting the idea of colour, it is clear that nothing more is necessary to account for the colours of bodies than to suppose each body endued with a power or aptitude to reflect the rays of one particular colour, and to imbibe the rest. But the truth of this does not rest on mere supposition. Bodies exposed to the uncompounded light of the spectrum, are ever found to be of the colour of the light in which they are

 placed,

placed, with this only difference, that they appear much more lively in that colour, which is the ſame with that which they exhibit in the day light. And from hence it appears, that the colours of bodies cannot be ſo homogeneous and full as thoſe of the ſpectrum, for ſince they reflect all colours in ſome degree as well as the principal or predominant one, that principal colour muſt be much diluted and weakened by the mixture. It may likewiſe from hence be inferred, that as the uncompounded colours are not changeable by refraction, ſo neither are they changeable by reflection.

The inſtance of the ſeparation of the primary colours of light which ſeems moſt remarkable, is that of the rainbow, which on that account was by the Grecians called Θαυμαντίς, or daughter of admiration. It is formed in general by the reflection of the rays of the Sun's light from the drops of falling rain, though frequently it appears among the waves of the ſea, whoſe heads or tops are blown by the wind into ſmall drops, and is ſometimes ſeen on the ground when the

the Sun ſhines on a very thick dew. Caſcades and fountains, whoſe waters are in their fall divided into drops, exhibit rainbows to a ſpectator, if properly ſituated during the time of the Sun's ſhining; and water blown violently out of the mouth of an obſerver, whoſe back is turned towards the Sun, never fails to produce the ſame phenomenon. This appearance is alſo ſeen by moonlight, though ſeldom vivid enough to render the colours diſtinguiſhable; and the artificial rainbow may be produced even by candle-light on the water which is ejected by a ſmall fountain or jet d'eau. All theſe are of the ſame nature, and dependant on the ſame cauſes, an idea of which may be formed by the following conſiderations.

Let the circle WQGB (fig. 63.) repreſent a globe or drop of water upon which a beam of parallel light falls, of which let TB repreſent a ray falling perpendicularly at B, and which by conſequence either paſſes through without refraction, or is reflected directly back from Q. Suppoſe another ray IK, incident at K, at a diſtance from B,

and it will be refracted according to a certain ratio of the ſines of incidence and refraction to each other (which in rain water is as 529 to 396) to a point L, whence it will be in part tranſmitted in the direction LZ, and in part reflected to M, where it will again in part be reflected, and in part tranſmitted in the direction MP, being inclined to the line deſcribed by the incident ray in the angle IOP. Another ray AN, ſtill farther from B, and conſequently incident under a greater angle, will be refracted to a point F, yet farther from Q, whence it will be in part reflected to G, from which place it will in part emerge, forming an angle AXR with the incident AN, greater than that which was formed between the ray MP and its incident ray. And thus, while the angle of incidence or diſtance of the point of incidence from B increaſes, the diſtance between the point of reflection and Q, and the angle formed between the incident and emergent reflected rays will alſo increaſe; that is to ſay, as far as it depends on that increaſe of incidence: but as the re-

fraction

fraction of the ray tends to carry the point of reflection towards Q, and to diminish the angle formed between the incident and emergent reflected ray, and that the more the greater the distance of the point of incidence from B, there will be a certain point of incidence between B and W, with which the greatest possible distance between the point of reflection and Q, and the greatest possible angle between the incident and emergent reflected ray will correspond. So that a ray incident nearer to B shall, at its emergence after reflection form a less angle with the incident, by reason of its more direct reflection from a point nearer to Q; and a ray incident nearer to W, shall at its emergence form a less angle with the incident, by reason of the greater quantity of the angles of refraction at its incidence and emergence. The rays which fall in the vicinity of that point of incidence with which the greatest angle of emergence corresponds, will, after emerging, form an angle with the incident rays which differs insensibly from that greatest angle, and consequently will proceed nearly parallel to each

other; and thoſe rays which fall at a diſtance from that point, will emerge at various angles, and conſequently will diverge. Now to a ſpectator, whoſe back is turned towards the radiant body, and whoſe eye is at a conſiderable diſtance from the globe or drop, the divergent light will be ſcarcely, if at all perceptible; but if the globe be ſo ſituated, that thoſe rays which emerge parallel to each other, or at the greateſt poſſible angle with the incident, may arrive at the eye of the ſpectator, he will, by means of thoſe rays, behold it nearly with the ſame ſplendor at any diſtance.

In like manner thoſe rays which fall parallel on a globe, and are emitted after two reflections (at the points, ſuppoſe F and G) do emerge (at H) parallel to each other, when the angle they make with the incident (AN) is the leaſt poſſible; and the globe is ſeen very reſplendent, when its poſition is ſuch, that thoſe parallel rays fall on the eye of the ſpectator.

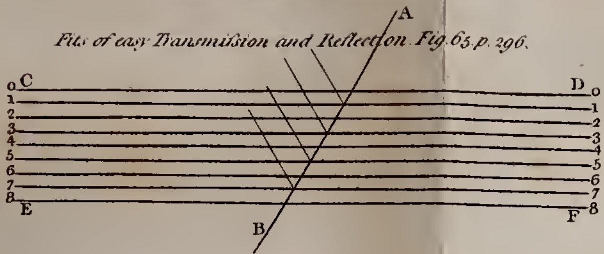
The quantity of this greateſt angle is determined by calculation, the proportion of the

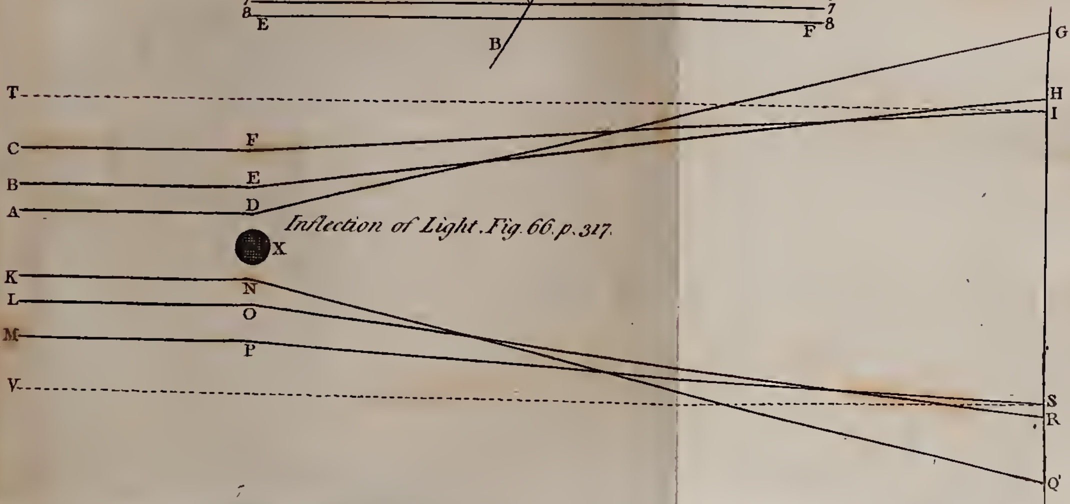
to face p.281. Vol. I.

No. XV.

Theory of the Rainbow. Fig. 64. p. 281.

Fits of easy Transmission and Reflection. Fig. 65. p. 296.





Inflection of Light. Fig. 66. p. 317.

the ſines of incidence and refraction to each other being known. And this proportion being different in rays which produce different colours, the angle muſt vary in each. Thus it is found, that its limit in rain-water for the leaſt refrangible, or red rays, emitted parallel after one reflection is 42° 2′, and for the moſt refrangible or violet rays emitted parallel after one reflection 40° 17′; likewiſe, after two reflections the leaſt refrangible or red rays will be moſt copiouſly emitted under an angle of 50° 57′, and the moſt refrangible or violet under an angle of 54° 7′; and the intermediate colours will be moſt copiouſly emitted at intermediate angles.

Suppoſe now, that O (fig. 64.) is the ſpectator's eye, and OP a line drawn parallel to the Sun's rays, and let POE, POF, POG, POH, be angles of 40° 17′, 42° 2′, 50° 57′, and 54° 7′ reſpectively, and theſe angles turned about their common ſide OP, ſhall, with their other ſides OE, OF, OG, OH deſcribe the verges of two rainbows as in the figure. For, if E, F, G, H be drops placed any where in the conical ſuperficies deſcribed by OE, OF, OG, OH, and be illuminated by the

the Sun's rays SE, SF, SG, SH; the angle SEO being equal to the angle POE, or 40° 17′, ſhall be the greateſt angle in which the moſt refrangible rays can, after one reflection, be refracted to the eye, and therefore all the drops in the line OE ſhall ſend the moſt refrangible rays moſt copiouſly to the eye, and thereby ſtrike the ſenſes with the deepeſt violet colour in that region. And in like manner the angle SFO being equal to the angle POF, or 42° 2′, ſhall be the greateſt in which the leaſt refrangible rays after one reflection can emerge out of the drops, and therefore thoſe rays ſhall come moſt copiouſly to the eye from the drops in the line OF, and ſtrike the ſenſes with the deepeſt red colour in that region. And, by the ſame argument, the rays which have the intermediate degrees of refrangibility ſhall come moſt copiouſly from drops between E and F, and ſtrike the ſenſes with the intermediate colours in the order which their degrees of refrangibility require; that is, in the progreſs from E to F, or from the inſide of the bow to the outſide, in this order, violet, indigo, blue, green, yellow, orange, red. But the violet, by

by the mixture of the white light of the clouds, will appear faint, and inclined to purple.

Again, the angle SGO being equal to the angle POG, or 50° 51′, ſhall be the leaſt angle in which the leaſt refrangible rays can, after two reflections, emerge out of the drops, and therefore the leaſt refrangible rays ſhall come moſt copiouſly to the eye from the drops in the line OG, and ſtrike the ſenſe with the deepeſt red in that region. And the angle SHO being equal to the angle POH, or 54° 7′, ſhall be the leaſt angle in which the moſt refrangible rays, after two reflections, can emerge out of the drops, and therefore thoſe rays ſhall come moſt copiouſly to the eye from the drops in the line OH, and ſtrike the ſenſes with the deepeſt violet in that region. And, by the ſame argument, the drops in the regions between G and H ſhall ſtrike the ſenſe with the intermediate colours in the order which their degrees of refrangibility require; that is, in the progreſs from G to H, or from the inſide of the bow to the outſide in this order, red, orange, yellow, green, blue, indigo, and violet. And ſince the four lines OE, OF, OG, OH may be

 ſituated

ſituated any where in the above-mentioned conical ſuperficies, what is ſaid of the drops and colours in theſe lines is to be underſtood of the drops and colours every where in thoſe ſuperficies.

Thus ſhall there be made two bows of colours, an interior and ſtronger, by one reflection in the drops, and an exterior and fainter by two; for the light becomes fainter by every reflection; and their colours ſhall lie in a contrary order to each other, the red of both bows bordering upon the ſpace GF, which is between the bows. The breadth of the interior bow, EOF, meaſured croſs the colours, ſhall be 1° 45′, and the breadth of the exterior, GOH, ſhall be 3° 10′, and the diſtance between them GOF, ſhall be 8° 55′, the greateſt ſemidiameter of the innermoſt, that is, the angle POF, being 42° 2′, and the leaſt ſemidiameter of the outermoſt POG being 50° 57′. Theſe are the meaſures of the bows, as they would be, were the Sun but a point; for, by the breadth of his body, the breadth of the bows will be increaſed, and their diſtance diminiſhed by half a degree, and ſo the breadth of the interior iris will be

2°

2° 15′, that of the exterior 3° 40′, their diſtance 8° 25′; the greateſt ſemidiameter of the interior bow 42° 17′, and the leaſt of the exterior 50° 42′. And ſuch are the dimenſions of the bows in the heavens found to be very nearly, when their colours appear ſtrong and perfect.

The light which comes through drops of rain by two refractions without any reflection ought to appear ſtrongeſt at the diſtance of about 26 degrees from the Sun, and to decay gradually both ways as the diſtance from him increaſes and decreaſes. And the ſame is to be underſtood of light tranſmitted through ſpherical hail-ſtones. And if the hail be a little flatted, as it often is, the light tranſmitted may grow ſo ſtrong at a little leſs diſtance than that of 26 degrees, as to form a halo about the Sun and Moon; which halo, as often as the ſtones are duly figured, may be coloured, and then it muſt be red within, by the leaſt refrangible rays, and blue without, by the moſt refrangible ones.

The light which paſſes through a drop of rain after two refractions, and three or more reflections, is ſcarce ſtrong enough to cauſe a ſenſible bow.

C H A P. VI.

Of the Separation of the original Rays of Light by Reflection or Tranſmiſſion, which depends on the Thickneſs of the Medium upon which they are incident.

THE original or component rays of light are ſeparable from each other, not only by refraction, or by varying the angle of incidence on a reflecting ſurface, but are likewiſe at like incidences more or leſs reflexible, according to the thickneſs or diſtance between the two ſurfaces of the medium on which they fall. They are alſo liable to be turned out of their direct courſe by approaching within a certain diſtance from a body, by which means a ſeparation enſues, the rays being more or leſs deflected as they differ in colour. Of theſe circumſtances it will be proper to give ſome account.

If a glaſs or lens, whoſe ſurface is convex, or a portion of a ſphere, be laid upon another plain glaſs, it is evident that it

will

will reſt or touch at one particular point only; and therefore, that at all other places between the adjacent ſurfaces will be interpoſed a thin plate of air, the thickneſs of which will increaſe in a certain ratio, according to the diſtance from the point of contact; that is to ſay, in arcs whoſe verſed ſines are very ſmall, as the diameter of the ſphere is to the ſine of the arc, ſo is that ſine to the verſed ſine or thickneſs of the air at the diſtance meaſured by the ſine.

Light incident upon ſuch a plate of air is diſpoſed to be tranſmitted or reflected according to its thickneſs: thus, at the center of contact, the light is tranſmitted, and a black circular ſpot appears; this ſpot is environed by a circle, the colours of which, reckoning from the internal part, are blue, white, yellow, red; then follows another circular ſeries, viz. violet, blue, green, yellow, red; then purple, blue, green, yellow, red; green, red; greeniſh blue, red; greeniſh blue, pale red; greeniſh blue, reddiſh white.

Theſe are the colours which appear by reflection: by the tranſmitted light the following ſeries are ſeen. At the center white, then yellowiſh

iſh red, black ; violet, blue, white, yellow, red ; violet, blue, green, yellow, red, &c. ſo that the tranſmitted light at any thickneſs, inſtead of white, appears of the compounded colour which it ought to have after the ſubtraction of ſome of the conſtituent colours by reflection ; after which ſeries the colours become too faint and dilute to be diſcerned. It is obſervable, that the glaſſes will not come into contact without a conſiderable degree of preſſure.

By admeaſurement it appears, that the rays of any particular colour are diſpoſed to be reflected when the thickneſſes of the plate of air are as the numbers 1. 3. 5. 7. 9. 11. &c. and that the ſame rays are diſpoſed to be tranſmitted at the intermediate thickneſſes, which are as the numbers 0. 2. 4. 6. 8. 10. &c.

The places of reflection or tranſmiſſion of the ſeveral colours in a ſeries are ſo near each other, that the colours dilute each other by mixture, whence the number of ſeries in the open day-light ſeldom exceeds ſeven or eight : but if the ſyſtem be viewed through a priſm, by which means the rings of various colours are ſeparated according to their refran-

refrangibilities, they may be ſeen on that ſide towards which the refraction is made, ſo numerous, that it is impoſſible to count them. Or, if in a dark chamber the Sun's light be ſeparated into its original rays by a priſm, and a ray of one uncompounded colour be received upon the two glaſſes heretofore deſcribed, the number of circles will become very numerous, and both the reflected and tranſmitted light will remain of the ſame colour as the original incident ray. In this experiment it alſo is ſeen, that in any ſeries, the circles formed by the leſs refrangible rays exceed in magnitude thoſe which are formed by the more refrangible rays, and conſequently that in any ſeries the leſs refrangible rays are reflected at leſs thickneſſes than thoſe which are more refrangible.

If the light be incident obliquely, the rings of colours dilate and enlarge themſelves; whence it follows, that the thickneſs required to reflect the colours of any ſeries is different in different obliquities.

Water, applied to the edges of the glaſſes, is attracted between them, and filling all the

intercedent ſpace, becomes a thin plate of the ſame dimenſions as that which before was conſtituted of air. In this caſe the rings become much fainter, but vary not in their ſpecies, and are contracted in diameter nearly in the proportion of 7 to 8: conſequently the intervals of the glaſſes at like circles cauſed by thoſe two mediums, water and air, are as about 3 to 4; that is, nearly as the ſines which meaſure the angles of incidence and refraction, made at a common ſurface between them. And hence it may be ſuſpected, that if any other medium, more or leſs denſe than water, be compreſſed between the two glaſſes, their intervals at the rings cauſed thereby will be to the intervals at which ſimilar rings are cauſed by the interjacent air, as the ſine which meaſures the refraction made out of air into that medium is to the ſine of the incidence on the common ſurface.

Theſe are ſome of the phenomena of light incident on mediums which are environed by mediums of greater denſity, as air or water compreſſed or included between plates of glaſs. The ſame appearances follow, though with

ſome little variation, when the colorific medium is denſer than that in which it is incloſed.

It is well known that bubbles blown in ſoap-water exhibit a great variety of colours; but as theſe colours are commonly too much agitated by the external air to admit of any certain obſervation, it is neceſſary that the bubble be covered with a clear glaſs; in which ſituation the following appearances enſue: the colours emerge from the vertex or top of the bubble, and as it grows thinner by the ſubſidence of the water, they dilate into circles or rings parallel to the horizon, which ſlowly deſcend and vaniſh ſucceſſively at the bottom. This emergence continues till the water at the vertex becomes too thin to reflect the light, at which time a circular ſpot of an intenſe blackneſs appears at the top, which ſlowly dilates ſometimes to $\frac{3}{4}$ of an inch in breadth before the bubble breaks. Reckoning from the black central ſpot, the reflected colours are the ſame in ſucceſſion and quality as thoſe produced by the aforementioned plate of air, and the appearance of the bubble, if viewed by tranſmitted light, is alſo ſimilar to that of the plate of air in like circumſtances.

If

If the colours be viewed with different obliquities, their place is changed, but not near ſo much as in the plate of air.

The end of a ſmall glaſs tube or pipe being melted, by turning the flame of a candle or lamp upon it, by means of a blow-pipe, may be blown into a bubble of an extreme thinneſs. Such a bubble will exhibit colours of the ſame kind as the foregoing, but much more briſk and lively. From which, and the premiſed obſervations, it is concluded, that a denſer medium incloſed by one that is rarer does exhibit more lively colours than thoſe which are produced by a rarer medium included in one that is more denſe. It is alſo obſervable, that the colours which are produced by reflection from, or tranſmiſſion through, denſe ſubſtances, do vary leſs by change of the obliquity of the incident light than they do in ſubſtances which are more rare.

By wetting very thin plates of Moſcovy glaſs, whoſe thinneſs occaſion the like colours to appear, the colours become more faint and languid, eſpecially if wetted on the ſurface oppoſite to the eye; but no variation of their ſpecies is produced: ſo that the thickneſs of any

any plate, requisite to produce any colour, depends only on the density of the plate, and not on that of the ambient medium: and hence may be known the thickness which thin plates of any transparent substance have at the place at which a given colour in any series is produced. For,

As the sine of the angle of incidence at the common surface
Is to the sine of the angle of refraction out of the given medium into air,
So is the thickness of a plate of air which exhibits the given colour
To the thickness of the given plate.

C H A P. VII.

General Inferences respecting the Disposition to be reflected or transmitted, into which the rays of Light are put, by the Action which depends on the Thickness of the Medium upon which they are incident.

THE experiments or observations in the last chapter being maturely weighed and considered, indicate the following theorem or general proposition; namely,

Every ray of light in its paſſage through any refracting ſurface is put into a certain tranſient conſtitution or ſtate, which in the progreſs of the ray returns at equal intervals, and diſpoſes the ray, at every return, to be eaſily tranſmitted through the next refracting ſurface, and, between the returns, to be eaſily reflected by it.

For, by thoſe obſervations it appears, that one and the ſame ſort of rays, at equal angles of incidence on any thin tranſparent plate, is alternately reflected and tranſmitted for many ſucceſſions; accordingly, as the thickneſs of the plate increaſes in arithmetical progreſſion of the numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, &c. ſo that if the firſt reflection, or that which makes the firſt or innermoſt ring of colours, be made at the thickneſs 1, the rays ſhall be tranſmitted at the thickneſſes 0, 2, 4, 6, 8, 10, 12, &c. and thereby make the central ſpot and rings of light which appear by tranſmiſſion, and be reflected at the thickneſſes 1, 3, 5, 7, 9, 11, &c. and thereby make the rings which appear by reflection. And this alternate reflection and tranſmiſſion continues for a great number of viciſſitudes, and by other obſervations, which for the ſake of brevity

brevity are omitted, for many thouſands, being propagated from one ſurface of a glaſs-plate to the other, though the thickneſs of the plate be a quarter of an inch or above: ſo that this alternation ſeems to be propagated from every refracting ſurface to all diſtances without end or limitation. And becauſe the ray is diſpoſed to reflection at the thickneſſes 1, 3, 5, 7, &c. and to tranſmiſſion at the thickneſſes 0, 2, 4, 6, 8, &c. for its tranſmiſſion through the firſt ſurface is at the diſtance 0, and it is tranſmitted through both together, if their diſtance be infinitely little, or much leſs than 1, the diſpoſition to be tranſmitted at the diſtances 2, 4, 6, 8, &c. is to be accounted a return of the ſame diſpoſition which the ray firſt had at the diſtance 0, that is, at its tranſmiſſion through the firſt refracting ſurface.

This alternate reflection and tranſmiſſion depends on both the ſurfaces of every thin plate, becauſe it depends on their diſtance. For if either ſurface of a thin plate of Moſcovy-glaſs be wetted, the colours grow faint: it muſt therefore depend upon both.

It is therefore performed at the ſecond ſurface; for if it were performed at the firſt,

 before

before the rays arrive at the ſecond, it would not depend on the ſecond.

It is alſo influenced by ſome action or diſpoſition, propagated from the firſt to the ſecond, becauſe otherwiſe at the ſecond it would not depend upon the firſt. And this action or diſpoſition, in its propagation, intermits and returns by equal intervals, becauſe in all its progreſs it inclines the ray at one diſtance from the firſt ſurface to be reflected by the ſecond, at another to be tranſmitted by it, and that, by equal intervals, for innumerable viciſſitudes.

The returns of the diſpoſition of any ray to be reflected are termed its fits of eaſy reflection, and thoſe of its diſpoſition to be tranſmitted its fits of eaſy tranſmiſſion; and the ſpace it paſſes through between every return, and the next return, the interval of its fits.

Thus, let CDFE (fig. 65.) repreſent a tranſparent medium, ſuppoſe water, upon which the ray AB is incident at a point in the upper ſurface o, o. Draw the line 1, 1, and let the interval between it and o, o be every where equal to the diſtance between the two ſurfaces of the plate of water, deſcribed in the laſt chapter, when the firſt ring of

colour

colour is reflected. Then, if the inferior ſurface of the medium were at 1, 1, the ray would be reflected upon the ſame principle as the ring of colour, and therefore at 1, 1 it is in a fit of eaſy reflection. Draw the parallel 2, 2 at the ſame diſtance from 1, 1, and the diſtance between 0,0, and 2, 2 will be that ſurface at which in the afore-mentioned plate the firſt ring of colour is tranſmitted: the ray would therefore be tranſmitted if the inferior ſurface were at 2, 2, and conſequently it is there in a fit of eaſy tranſmiſſion. At 3, 3 it is again in a fit of eaſy reflection, and by applying the ſame argument to the equidiſtant lines 4, 4; 5, 5; 6, 6; 7, 7; 8, 8; it will appear that the ray will be alternately diſpoſed to tranſmiſſion and reflection; and if the laſt parallel or the inferior ſurface be diſtant from the ſuperior ſurface 0, 0, by an even number of intervals, the ray will arrive there in a fit of eaſy tranſmiſſion and emerge; but if the number be odd, it will arrive in a fit of eaſy reflection, and return back into the medium. The diſtance between the lines 0,0 and 2, 2; 2, 2 and 4, 4, &c. are the intervals of the fits of eaſy tranſmiſſion, and the diſtances

tances between 1, 1 and 3, 3; 3, 3 and 5, 5, &c. are the intervals of the fits of easy reflection.

What kind of action or disposition this may be, whether it consist in a circulating or a vibrating motion of the ray or of the medium, or something else, experiments are wanting to determine. But the facts are not the less true on account of our ignorance of the mode of their origin. That truly great man, to whose penetration and industry we are indebted for almost all the knowledge we have of the physical properties of light, has, with great modesty, proposed an hypothesis for the solution of these appearances. It is not without its difficulties, and must therefore be received with the same caution as it was proposed, till experiment shall either confirm it, or substitute another theory in its place.

The Hypothesis. It may be supposed, that as stones by falling into water put the water into an undulating motion, and all bodies by percussion excite vibrations in the air; so the rays of light, by impinging on any refracting or reflecting surface, excite vibrations in the refracting or reflecting medium or substance, and by exciting them, agitate the

the solid parts of the refracting or reflecting body, and by agitating them, cause the body to grow warm or hot; that the vibrations thus excited are propagated in the refracting or reflecting medium or substance much after the manner that vibrations are propagated in the air for causing sound, and move faster than the rays, so as to overtake them; and that when any ray is in that part of the vibration which conspires with its motion, it easily breaks through a refracting surface, but when it is in the contrary part of the vibration which impedes its motion, it is easily reflected; and, by consequence, that every ray is successively disposed to be easily reflected or easily transmitted by every vibration which overtakes it.

CHAP. VIII.

Of the permanent Colours of natural Bodies, and the Analogy between them and the Colours of thin transparent Plates.

IT has already been shewn, that the colours of natural bodies consist in a disposition to reflect the rays of one sort of light more copiously than the rest. But their constitu-

tion,

tion, whereby they reflect ſome rays more copiouſly than others, remains to be diſcloſed; which ſhall be the buſineſs of the preſent chapter.

Thoſe ſuperficies of tranſparent bodies reflect the greateſt quantity of light, which have the greateſt refracting power; that is, which intercede mediums that differ moſt in their refractive denſities. And in the confines of equally refracting mediums there is no reflection.

The analogy between reflection and refraction will appear by conſidering that the moſt refractive mediums do totally reflect the rays of light at leſs angles of incidence, as was before ſhewn. But the truth of the propoſition will further appear by obſerving, that in the common ſuperficies of two tranſparent mediums, the reflection is ſtronger or weaker accordingly as the ſuperficies hath a greater or leſs refractive power. If any tranſparent ſolid be immerged in water, its reflection becomes much weaker than before, and ſtill weaker if immerged in a fluid whoſe refracting power is yet ſtronger than that of water. If water be diſtinguiſhed into two parts by an imagi-

nary

nary ſurface, the reflection in the confine of thoſe two parts is none at all. In the confine of water and ice it is very little; in that of water and oil ſomething greater; in that of water and ſal-gemm ſtill greater; and in that of water and glaſs, or cryſtal, or other denſer ſubſtances ſtill greater, accordingly as thoſe mediums differ more or leſs in their refractive powers. The reaſon then why uniform pellucid mediums, as water, glaſs or cryſtal, have no ſenſible reflection, but at their external ſuperficies, where they are adjacent to other mediums of a different denſity, is that all their contiguous parts have one and the ſame degree of denſity.

The leaſt parts of almoſt all natural bodies, are in ſome meaſure tranſparent: and the opacity of bodies ariſes from the multitude of reflections cauſed in their internal parts.

This may be eaſily ſeen by viewing ſmall ſubſtances with the microſcope or magnifying glaſs, for they appear for the moſt part tranſparent. And it may alſo be tried by means of the light intromitted through a hole into a dark chamber. For any ſubſtance, how

opake

opake ſoever, if it be reduced to a ſufficient thinneſs, and applied to the hole, will appear manifeſtly tranſparent. Only white metalline bodies muſt be excepted, which by reaſon of their very great denſity, ſeem to reflect almoſt all the light incident on their firſt ſuperficies, unleſs by ſolution in menſtruums, they be reduced into very ſmall particles, and then they alſo become tranſparent.

Between the parts of opake or coloured bodies are many ſpaces, either empty or repleniſhed with mediums of other denſities; as water between the tinging corpuſcles with which any liquor is impregnated, air between the aqueous globules that conſtitute clouds and miſts; and for the moſt part, ſpaces void both of air and water, but yet, perhaps, not void of all ſubſtance, between the parts of hard bodies.

The truth of this is evinced by the two precedent propoſitions: for, by the ſecond, there are many reflections made by the internal parts of bodies, which would not happen if the parts of thoſe bodies were continued without any ſuch interſtices between them

them; becauſe reflections are only made in ſuperficies which intercede mediums of different denſities.

A yet farther proof that the opacity of bodies ariſes from this diſcontinuation of their parts may be had, by conſidering that opake ſubſtances become tranſparent, by filling their pores with any ſubſtance of an equal or nearly equal denſity with their parts. Thus, paper dipped in water or oil, the oculus mundi ſtone ſteeped in water, linen cloth oiled or varniſhed, and many other ſubſtances ſoaked in ſuch liquors as will intimately prevade their pores, become by that means more tranſparent than otherwiſe; ſo, on the contrary, the moſt tranſparent ſubſtances may, by evacuating their pores, or ſeparating their parts, be rendered ſufficiently opake, as ſalts, or wet paper, or the oculus mundi ſtone, by being dried; horn, by being ſcraped; glaſs, by being reduced to powder, or otherwiſe flawed; turpentine, by being ſtirred about with water till they mix imperfectly; and water, by being formed into many ſmall bubbles, either alone in the form of froth, or by ſhaking it together with oil of turpentine,

tine, or ſome other convenient liquor with which it will not perfectly incorporate.

The parts of bodies and their interſtices muſt not be leſs than ſome definite bigneſs, to render them opake and coloured.

For the opakeſt bodies, if their parts be ſubtilely divided, as metals, by being diſſolved in acid, menſtruums, &c. become perfectly tranſparent. And it may alſo be remembered, that the black ſpot near the point of contact of the two plates of glaſs being of ſome conſiderable breadth, tranſmitted the whole light where the glaſſes did not abſolutely touch. And the reflection at the thinneſt part of the ſoap bubble was ſo inſenſible as to make that part appear intenſely black, by the want of reflected light.

On theſe grounds it is, that water, ſalt, glaſs, ſtones, and ſuch like ſubſtances are tranſparent. For on many conſiderations they ſeem to be as full of pores or interſtices between their parts as other bodies are, but yet their parts and interſtices to be too ſmall to cauſe reflection in their common ſurfaces.

The tranſparent parts of bodies, according to their ſeveral ſizes, muſt reflect rays of one

 colour,

colour, and tranſmit thoſe of another, on the ſame ground that thin plates or bubbles do reflect or tranſmit thoſe rays. And this is the ground of all their colours.

For if a thin body or plate, which, being of an even thickneſs, appears all over of one uniform colour, ſhould be ſlit into threads or broken into fragments of the ſame thickneſs with the plate, there is no reaſon why every thread or fragment ſhould not keep its colour, and by conſequence, why a heap of thoſe threads or fragments ſhould not conſtitute a maſs or powder of the ſame colour which the plate exhibited before it was broken. And the parts of all bodies being like ſo many fragments of a plate, muſt on the ſame grounds exhibit the ſame colours.

Now that they do ſo, will appear by the affinity of their properties. The finely coloured feathers of ſome birds, and particularly thoſe of peacocks tails, do in the very ſame part of the feather appear of ſeveral colours in ſeveral poſitions of the eye. Likewiſe the fine-ſpun webs of ſome ſpiders appear coloured; and the fibres of ſome ſilks, by varying the poſition of the eye, do vary their colours.

 Alſo

Alſo the colours of ſilks, cloths, and other ſubſtances which liquids can eaſily penetrate, become more faint by being wetted, much after the manner of the plate of Moſcovy glaſs, and recover their vigour again by being dried. In like manner, if we conſider the various phenomena of the atmoſphere, we may obſerve, that when vapours are firſt raiſed, they hinder not the tranſparency of the air, being divided into parts too ſmall to cauſe any reflection at their ſuperficies. But when, in order to compoſe drops of rain, they begin to coaleſce, and conſtitute globules of all intermediate ſizes, thoſe globules, when they become of a convenient ſize to reflect ſome colours and tranſmit others, may conſtitute clouds of various colours, according to their ſizes. And in fact, it is difficult to conceive any thing or property in ſo tranſparent a body as water for the production of theſe colours, except the various ſizes of its fluid and globular parcels.

The parts of bodies, on which their colours depend, are denſer than the medium which prevades their interſtices.

For if they were not, the variation of colour, ariſing from the various obliquities of the incident light, would compound a mixt and imperfect colour, and never ſo vivid as experience evinces. But when the parts are much denſer than the ambient medium this variation is not ſo conſiderable; and therefore the rays which are reflected leaſt obliquely may predominate over the reſt, ſo much as to cauſe a heap of ſuch particles to appear very intenſely of their colour.

And hence the magnitude of the component parts of natural bodies may be conjectured by their colours.

For, ſince the parts of theſe bodies are of about the ſame denſity as water or glaſs, as by many circumſtances is obvious to collect, it is highly probable that they exhibit the ſame colours with a plate of equal thickneſs. That colour being known, the thickneſs may be eaſily found by the preceding obſervations.

CHAP. IX.

Of the Powers by which Bodies reflect or refract the Rays of Light.

THE reflection of light is not caufed by its impinging or ftriking on the folid parts of bodies.

This will appear by the following confiderations. Firft, That in the paffage of light out of glafs into air, there is a reflection as ftrong as in its paffage out of air into glafs, or rather a little ftronger, and by many degrees ftronger than in its paffage out of glafs into water. And it feems not probable, that air fhould have more reflecting parts than water or glafs. But if that fhould poffibly be fuppofed, yet it will avail nothing; for the reflection is as ftrong or ftronger, when the air is drawn away from the glafs, as when it is adjacent to it. Secondly, If light in its paffage out of glafs into air be incident more obliquely than at an angle of 40 or 41 degrees, it is wholly reflected; if lefs obliquely, it is in

in a great meaſure tranſmitted. Now it is not to be imagined that light, at one degree of obliquity, ſhould meet with pores enough in the air to tranſmit the greater part of it, and at another degree of obliquity, ſhould meet with nothing but parts to reflect it wholly; eſpecially conſidering that in its paſſage out of air into glaſs, how oblique ſoever be its incidence, it finds pores enough in the glaſs to tranſmit the greateſt part of it. If any one ſuppoſe that it is not reflected by the air, but by the outmoſt ſuperficial parts of the glaſs, there is ſtill the ſame difficulty: beſides, that ſuch a ſuppoſition is unintelligible, and will alſo appear to be falſe, by applying water behind ſome part of the glaſs inſtead of air. For ſo in a convenient obliquity of the rays, ſuppoſe of 45 or 46 degrees, at which they are all reflected where the air is adjacent to the glaſs, they ſhall be in great meaſure tranſmitted where the water is adjacent to it; which argues that their reflection depends on the conſtitution of the air and water behind the glaſs, and not in the ſtriking of the rays upon the parts of the glaſs. Thirdly, If the colours made by a

prifm placed at the entrance of a beam of light into a darkened room be fucceffively caft on a fecond prifm placed at a diftance from the former, in fuch manner that they are all alike incident upon it, the fecond prifm may be fo inclined to the incident rays, that thofe which are of a blue colour fhall be all reflected by it, and yet thofe of a red colour pretty copioufly tranfmitted. Now, if the reflection be caufed by the parts of air or glafs, it may be demanded why, at the fame obliquity of incidence, the blue fhould wholly impinge on thofe parts, fo as to be all reflected, and yet the red find pores enough to be in great meafure tranfmitted. Fourthly, Where two glaffes touch one another there is no fenfible reflection, as was before obferved; and yet no reafon can be given why the rays fhould not impinge on the parts of the glafs as much when contiguous to other glafs as when contiguous to air. Fifthly, When the top of a foap water bubble, by the continual fubfiding and exhaling of the water, becomes very thin, there is fuch a little and almoft infenfible quantity of light reflected from it, that it appears intenfely

black; whereas, round about that black ſpot, where the water is thicker, the reflection is ſo ſtrong as to make the water ſeem very white. Nor is it only at the leaſt thickneſs of thin plates or bubbles, that there is no manifeſt reflection, but at many other thickneſſes continually greater and greater. For the rays of the ſame colour are by turns tranſmitted at one thickneſs, and reflected at another thickneſs for an indeterminate number of ſucceſſions. And yet, in the ſuperficies of the thin body, where it is of any one thickneſs, there are as many parts for the rays to impinge on, as where it is of any other thickneſs. Sixthly, If reflection were cauſed by the parts of reflecting bodies, it would be impoſſible for thin plates or bubbles at the ſame place to reflect the rays of one colour, and tranſmit thoſe of another. For it is not to be imagined, that at one place the rays which, for inſtance, exhibit a blue colour, ſhould have the fortune to daſh upon the parts, and thoſe which exhibit a red to hit upon the pores of the body; and then at another place, where the body is either

a little thicker or a little thinner, that on the contrary, the blue ſhould hit upon its pores, and the red upon its parts. Laſtly, Were the rays of light reflected by impinging on the ſolid parts of bodies, their reflections from poliſhed bodies could not be ſo regular as they are. For in poliſhing glaſs with ſand, putty, or tripoly, it is not to be imagined that thoſe ſubſtances can, by grating and fretting the glaſs, bring all its leaſt particles to an accurate poliſh, ſo that all their ſurfaces ſhall be truly plane or truly ſpherical, and look all the ſame way ſo as together to compoſe one even ſurface. The ſmaller the particles of thoſe ſubſtances are, the ſmaller will be the ſcratches by which they continually fret and wear away the glaſs until it be poliſhed; but be they ever ſo ſmall, they can wear away the glaſs no otherwiſe than by grating and ſcratching it, and breaking the protuberances, and therefore poliſh it no otherwiſe than by bringing its roughneſs to a very fine grain, ſo that the ſcratches and frettings of the ſurface become too ſmall to be viſible. And therefore, if light were reflected by impinging upon the

 ſolid

ſolid parts of the glaſs, it would be ſcattered as much and as irregularly by the moſt poliſhed glaſs as by the rougheſt. So then it remains a problem, how glaſs poliſhed by fretting ſubſtances can reflect light ſo regularly as it does. And this problem is ſcarce otherwiſe to be ſolved than by ſaying, that the reflection of a ray is effected not by a ſingle point of the reflecting body, but by ſome power of the body which is evenly diffuſed all over its ſurface, and by which it acts upon the ray without immediate contact: for that the parts of bodies do act upon light at a diſtance ſhall be ſhewn hereafter.

Now if light be reflected, not by impinging on the ſolid parts of bodies, but by ſome other principle, it is probable that as many of its rays as impinge on the ſolid parts of bodies are not reflected, but ſtifled or loſt in the bodies. For otherwiſe, we muſt allow two ſorts of reflections. Should all the rays be reflected which impinge on the ſolid parts of clear water or cryſtal, thoſe ſubſtances would rather have a cloudy colour than a clear tranſparency. To make bodies look

black

black in all poſitions, it is neceſſary that many rays be ſtopped, retained, and loſt in them; and it is difficult to conceive that any rays can be ſtopt and ſtifled in them which do not impinge on their parts.

Bodies reflect and refract light by one and the ſame power, variouſly exerciſed in various circumſtances.

This appears by ſeveral conſiderations. Firſt, Becauſe when light goes out of glaſs into air as obliquely as it can poſſibly do, if its incidence be made ſtill more oblique, it becomes totally reflected. For the power of the glaſs, after it has refracted the light as obliquely as is poſſible, if the incidence be ſtill made more oblique, becomes too ſtrong to let any of its rays go through, and by conſequence cauſes total reflection. Secondly, Becauſe light is alternately reflected and tranſmitted by thin plates of glaſs for many ſucceſſions, accordingly as the thickneſs of the plate increaſes in an arithmetical progreſſion. For here the thickneſs of the glaſs determines whether that power by which glaſs acts upon light ſhall cauſe it to be reflected, or ſuffer it to be tranſmitted. And thirdly, Becauſe

thoſe

thoſe ſurfaces of tranſparent bodies which have the greateſt refracting power do alſo reflect the greateſt quantity of light, as was ſhewn in the firſt propoſition of this chapter.

CHAP. X.

Of the Inflections of the Rays of Light which paſs in the Vicinities of Bodies.

IT is obſervable, that if a beam of the Sun's light be let into a dark room through a very ſmall hole, the ſhadows of things in this light will be larger than they ought to be if the rays went on by the bodies in ſtrait lines, and that theſe ſhadows have three parallel fringes, bands, or ranks of colours adjacent to them. The principal circumſtances of the phenomenon are as follow.

If a beam of the Sun's light be admitted into a darkened chamber through a hole of the breadth of the forty-ſecond part of an inch, or thereabouts, the ſhadows of hairs, thread, ſtraws, and other ſmall bodies appear conſi-

derably

derably broader than they would be if the light paſſed by them in ſtrait lines. For example; a hair, whoſe breadth was the 280th part of an inch, being held in this light at the diſtance of about twelve feet from the hole, did caſt a ſhadow which, at the diſtance of four inches from the hair, was the ſixtieth part of an inch broad, that is, above four times broader than the hair; and at the diſtance of ten feet, was the eighth part of an inch broad, that is, thirty-five times broader.

Nor is the effect altered by an alteration in the denſity of the medium contiguous to the hair, for its ſhadow at like diſtances was equal, whether it was in the open air or incloſed between two plates of wet glaſs, care being had that the incidence and emergence of the ray was perpendicular to the glaſſes. Scratches on the ſurface or veins in the body of poliſhed glaſſes did alſo caſt the like broad ſhadows. And therefore the great breadth of theſe ſhadows muſt proceed from ſome other cauſe than the uſual refraction which might ariſe from any action of the ambient medium.

Let

Let the circle X (fig. 66.) represent the middle of the hair; ADG, BEH, CFI, three rays passing by one side of the hair at several distances; KNQ, LOR, MPS, three other rays passing by the other side of the hair at the like distances; D, E, F, and N, O, P, the places where the rays are bent in their passage by the hair; G, H, I, and Q, R S, the places where the rays fall on a paper, GQ; IS the breadth of the shadow of the hair cast on the paper; and TI, VS, two rays which fall on the points I and S, without being at all deflected by the action of the hair. Then it is manifest that all the rays between TI and VS are bent in passing by the hair, and turned aside from the shadow IS, because if any part of the light were not bent it would fall within the shadow, and there illuminate the paper, contrary to experience. And because, when the paper is at a great distance from the hair, the shadow is broad, and therefore the rays TI and VS are at a great distance from each other, it follows that the hair acts upon the rays of light at a considerable distance in their passing by it. But because the shadow of the hair is much broader

broader in proportion to the diſtance of the paper from the hair when the paper is nearer to the hair than when it is at a great diſtance from it, it is evident that the action is ſtronger on the rays which paſs by at leaſt diſtances, and grows weaker and weaker accordingly as the rays paſs by at diſtances greater and greater, as is repreſented in the ſcheme.

The ſhadows of all bodies in this light are bordered with three parallel fringes or bands of coloured light, of which that contiguous to the ſhadow is broadeſt and moſt luminous, and that moſt remote from it is narroweſt, and ſo faint as ſcarcely to be viſible. If the light be received very obliquely on paper, or any other ſmooth white body, the colours may be plainly diſtinguiſhed in this order, viz. the firſt or innermoſt fringe is violet and deep blue next the ſhadow, and then light blue, green and yellow in the middle, and red without. The ſecond fringe is almoſt contiguous to the firſt, and the third to the ſecond, and both are blue within, and yellow and red without, but their colours are very faint, eſpecially thoſe of the third. The colours therefore proceed in this order from the ſhadow,

violet,

violet, indigo, pale blue, green, yellow, red; blue, yellow, red; pale blue, pale yellow, and red.

If a larger beam of the Sun's light be admitted into a dark chamber, and part of it received on the blade of a ſharp knife, whoſe plane interſects the direction of the beam at right angles, while the other part is ſuffered to paſs by the edge of the knife, and received on a paper at the diſtance of about three feet, this laſt light will appear to ſhoot out or ſend forth two faint luminous ſtreams both ways into the ſhadow, ſomewhat like the tails of comets. Theſe ſtreams being very faint, are ſo much obſcured by the light of the principal direct rays, that it is neceſſary, in order to ſee them with any degree of diſtinctneſs, to let the direct rays paſs through a hole in the paper on to a piece of black cloth. The light of the ſtreams is then perceptible on the paper to the diſtance of ſix or eight inches from the Sun's direct light each way, and in all the progreſs from that direct light decreaſes gradually till it becomes inſenſible.

If two knife-blades, with ſtrait edges, be ſo fixed or ſet in a frame, that they may both

be

be ſituated in the ſame plane, their edges parallel, and facing each other, and one of the blades moveable towards or from the other by means of a ſcrew, ſo that their paralleliſm may be always preſerved, a beam of light may be ſuffered to paſs between their edges, and the appearances are the following: when the knives are at a conſiderable diſtance, ſo that the intromitted beam is broad, the ſtreams of light which ſhoot both ways into the ſhadow are ſcarce viſible, for the reaſon already mentioned, and the edges of the ſhadows are not bordered with coloured fringes, they becoming ſo broad that they run into each other, and by joining form one continued light or whiteneſs at the beginning of the ſtreams. As the knives approach each other the fringes of colour appear on the confine of each ſhadow, becoming diſtincter and larger until they vaniſh, which happens when the edges are diſtant ſomewhat more than the 400th part of an inch. After the fringes have diſappeared, the line of light, which was in the middle between them, grows very broad, enlarging itſelf both ways into the ſtreams of light afore-mentioned; and when the

the knives are diſtant above the 400th part of an inch, the light parts in the middle, and leaves a ſhadow between the two parts. And as the knives ſtill approach each other, the ſhadow grows broader, and the ſtreams ſhorter at their inward ends, which are contiguous to the ſhadow, till upon the contact of the knives the whole light vaniſhes, leaving its place to the ſhadow.

From theſe and ſome other experiments of the ſame tendency, there is reaſon to ſuſpect,

That all bodies act upon the particles of light attracting them when within a certain diſtance, and at greater diſtances repelling them; for the two comet-like ſtreams ſeem to be produced, the one by an attractive power exerted, by which the light is thrown into the ſhadow of the knife, and the other by a repulſion, by which it is turned towards the contrary part or region.

That theſe actions are ſtronger on thoſe rays which paſs nearer the body than on thoſe which paſs at greater diſtances: conſequently thoſe rays which were parallel before their arrival in the vicinity of the body being variouſly deflected, muſt, after paſſing, di-

verge from each other; and, at the limit or diſtance at which attraction ceaſes, and repulſion begins, there muſt be a place at which the paſſing rays being very little affected by the action of the body, will proceed parallel, as before their arrival in its vicinity.

That this limitation or diſtance may differ in rays of different colours, and cauſe the appearance of fringes: for, if the limit be leſs in the violet rays than in the red rays, the parallel rays of the violet colour will form a fringe, which ſhall be nearer the ſhadow of the body than that which is formed by the parallel rays of the red colour: and ſo of the intermediate colours will be formed intermediate fringes. But it muſt be confeſſed, that this ſuppoſition does not account for the repetition of the ſame colour at different diſtances.

That the rays of light are not refracted or reflected all at once, but in refraction gradually bent into a curve by the action of the body, ſo as to enter its ſurface more perpendicularly than they otherwiſe would have done. And in reflection, that the repulſive force acting in the direction of the perpendicular

cular from the body, does not destroy the motion of the ray all at once, but bends it back in a curve. Which repulsion, when it has destroyed that part of the motion of the ray which tended perpendicularly towards the body, must reflect the ray with an equal angle and degree of velocity on the opposite side of the perpendicular to the point of incidence, or vertex of the curve. This is evident from what has already been said on the composition and resolution of motion; and may be familiarly illustrated by conceiving a body obliquely projected from the earth to be repelled by an imaginary horizontal plane situated above the curve of its motion, which in effect answers to an attraction by the earth; for the ascending or perpendicular part of the motion is gradually destroyed by the continually acting force, and a new, similar and equal motion is generated in the contrary direction, which causes the body to fall under an equal angle, and with the same velocity.

Since action and re-action are equal, the particles of light, being attracted or repelled by the adjacent parts of bodies, must also re-act on those parts. This re-action may cause that

vibration or agitation in which the quality of heat does probably consist.

If the attractive forces of bodies upon the particles of light be supposed to act equally after the ratio of the masses of the particles, the rays will be all equally refracted, however different their masses, provided their velocities be equal. If the same law of the attraction be supposed, and the velocities of the particles be various, those which move with less velocities will be more refrangible than those which move with greater velocities. The varying refrangibility of the rays of light must arise either from the various velocities of the particles themselves, or from the action of bodies on the particles being stronger on some than on others, after the ratio of their masses. If the various velocities were the cause of the different refrangibility of light, the moons of Jupiter, after being eclipsed, ought to appear illuminated with a variety of colours, in succession, as the velocities of their constituent rays caused them respectively to arrive at the eye of the observer: and when light is dispersed, by refraction, into its component colours, the quantity of this dispersion would

would in all cafes follow the proportion of the mean refraction of the whole ray: both which are contrary to experience: whence it follows, that, in order to produce the variety of refraction which happens in the feveral rays of light, bodies muft act on fome of the particles of light more ftrongly than upon others, after the ratio of their maffes.

After all, it may reafonably be concluded, that our knowledge of the properties of light is yet far from perfection. Reflection, refraction, inflection, and colour, may not be the only affections or accidents to which it is fubjected; and thefe are not well underftood. The firft of philofophers, Sir Ifaac Newton, whofe difcoveries are the boaft and glory of thefe later ages, has left the fubject unfinifhed; and though feveral ingenious men have attended to it, nothing of any great confequence has been done fince his time: we therefore recommend to the reader, who wifhes to fee a more accurate and particular account of the matters which are treated of in this fection, the perufal of his book, which is intitled, "Optics, or a Treatife on the Reflexions, Refractions, Inflections and Colours of Light."

BOOK II.

SECT. II.

Of Optics.

CHAP. I.

Of the Reflection and Refraction of Light by Surfaces regularly formed.

FOR many centuries, the ſcience of optics conſiſted only of conſequences drawn from the principles eſtabliſhed at Chap. 3. Sect. 1. of this Book; the compounded nature of light not being even ſuſpected. And, indeed, though that is one of the principal impediments to the perfection of the

the large and accurate instruments of modern times, yet we may, in common speech, regard a ray of white light, when refracted, as still continuing white; the colours of the spectrum into which it is dilated being so near, when the incidence is near the perpendicular, that, to sense, they form a white very little differing from that of the incident ray.

That bodies are visible only by means of the light which they emit or reflect, is too evident to need any particular proof; and that every point of an illuminated surface does emit the rays of light in all directions, is clear from the visibility of the surface, to an eye in any position whatsoever: for if any part or sensible point of the surface did not emit light in a supposed or given direction, that point, to an eye properly placed, must be invisible. But this effect never happens.

The rays which proceed from a point are always divergent, but if they fall on a reflecting or refracting surface, they may be irregularly scattered in such directions as the construction of the surface produces. If the surface be properly formed, they may proceed, after reflection or refraction, either

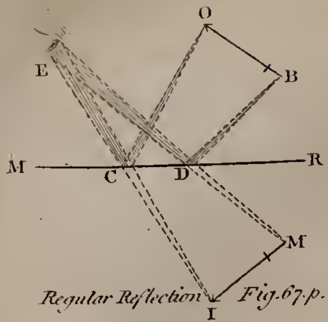
diverging from ſome other point, or parallel, or converging to a point.

When the rays which proceed from any point are conſidered, that point is called the radiant point; when the rays which proceed towards any point are conſidered, that point is called the focus; and when the rays which proceed from a whole ſurface or object, are conſidered, the *faſcis* or body of rays which is emitted from any one point, or as much of it as is applied to uſe, is called a pencil of rays.

Since a pencil of rays, emanating from any given point of ſpace, is the means by which the ſight aſſures us that a body or ſubſtance exiſts at or in that point, it is plain that we are liable to deception in that reſpect: for if the pencil be ſo affected, either by reflection or refraction, as to proceed with a different divergency or direction, that is, in the ſame manner as it would have proceeded if emitted from ſome other point of ſpace, the ſenſe will refer the place of the object to the point which is in the direction of the laſt courſe of the rays.

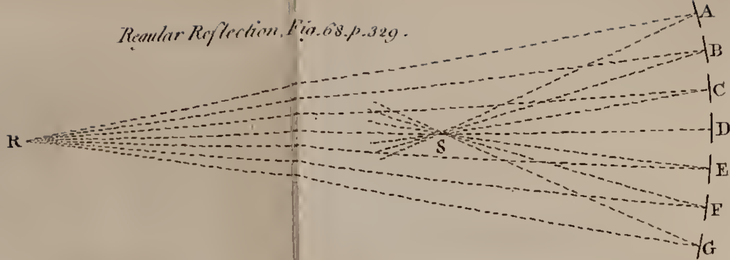
 Thus,

N° XVI.

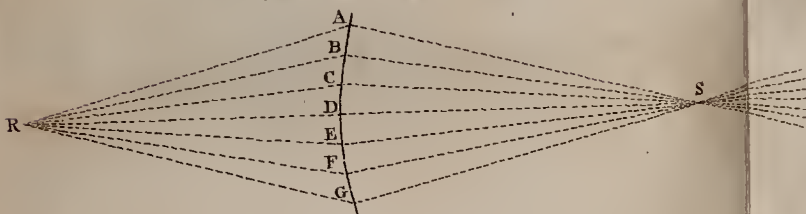


Regular Reflection Fig.67.p.329.

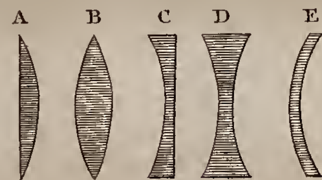
Regular Reflection. Fig.68.p.329.



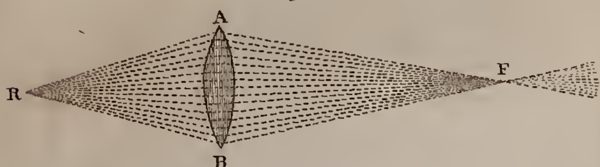
Regular Refraction. Fig.69.p.333.



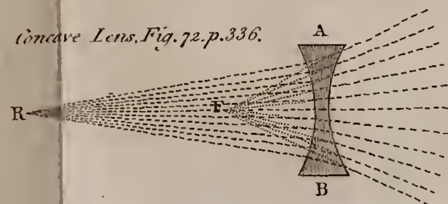
Lenses Fig.70.p.335.



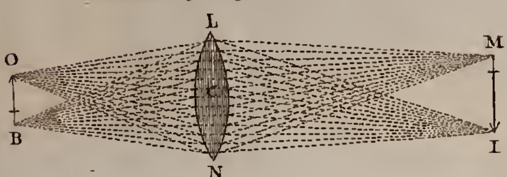
Convex Lens. Fig.71.p.335.



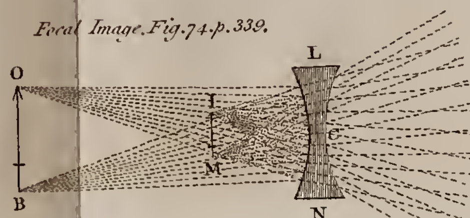
Concave Lens. Fig.72.p.336.



Focal Image Fig.73.p.338.



Focal Image. Fig.74.p.339.



Thus, if MR (fig. 67.) represent the section of a plane mirror, and OB an object, then the pencils OC and BD being reflected at C and D, will proceed to the eye at E, in the same manner as if emitted from points situated at I and M, and the same happening to the pencils which are emitted from the intermediate points between O and B, the sense will refer the place of the object to IM. The same happens by refraction, as is clear from the consideration of fig. 56.

If a pencil of rays be rendered convergent, so as to meet and cross each other in a point, they will afterwards diverge, and the sense will refer the place of the radiant point or object to the focus of the convergent rays, from which the divergence was last made; and, that rays of any sort may be rendered thus convergent, either by reflection or refraction, is easily shewn.

Suppose R (fig. 68.) to be a point, in any illuminated or luminous object, which emits a pencil consisting of seven rays of light, RA, RB, RC, RD, RE, RF, RG; let the ray RA be received on a speculum, so placed as to reflect it through the point S: let another speculum

ſpeculum be adapted to receive and reflect RB alſo through S; and, in like manner, let the other rays be reflected through the ſame point; and the point S will become a radiant point, by means of the divergent rays, and will affect the ſenſe in the ſame manner as if the rays actually emanated from a body placed there. If the ſpeculums be ſuppoſed to touch each other, they will form a polygonal concavity. Suppoſe now the number of rays, inſtead of ſeven, to be infinite; then the adapted reflecting ſurface AG, inſtead of polygonal, muſt become curve, by reaſon of the infinite number of ſides. The ſame reaſoning may be applied to rays, which, inſtead of emanating from a point, or diverging, do incide, either converging to a point, or parallel to each other. It is therefore poſſible to conſtruct a ſuperficies that ſhall reflect into a focus the rays of light, which, either by converging or diverging, do reſpect any particular point.

Upon the ſame principles may be conſtructed ſpeculums, which ſhall cauſe the rays, after reflection, to diverge from any given point behind the reflecting ſurface. Thoſe

Thoſe ſpeculums, which cauſe the rays to diverge, will be in general convex, and thoſe which cauſe them to converge, will be in general concave, as may eaſily be conceived,

The celebrated Archimedes, at the ſiege of Syracuſe, is ſaid to have deſtroyed the ſhips of Marcellus, by a machine compoſed of ſpeculums. Since a plane ſpeculum, in theory, reflects all the light which is incident upon it, under the ſame affections with which it was incident; the rays of the Sun, which, as coming from a vaſtly diſtant object, may be eſteemed parallel, will be reflected parallel to each other; and conſequently will heat and illuminate any ſubſtance on which they fall after reflection, in the ſame manner as if the Sun ſhone directly upon it. Two ſpeculums, which reflect the Sun's light on the ſame ſubſtance, will heat it twice as much as the Sun's direct light. Three will, in like circumſtances, heat it three times as much. And, by increaſing the number of ſpeculums, a prodigious degree of heat may be produced; more than ſufficient to conſume and deſtroy any inflammable ſubſtance.

We

We have ſaid *in theory*, that a plane ſpeculum reflects all the light which incides upon it; but in practice almoſt half the light is loſt, on account of the inaccuracy of the poliſh, and the opacity of the ſubſtance of the mirror; by means of which, a conſiderable part of the light is ſcattered in all directions, and another part is abſorbed by the body. The indefatigable *Buffon*, in the year 1747, was the firſt of the moderns who conſtructed a burning machine of this kind. It conſiſted of 168 glaſſes or ſpecula, each 8 inches long and 6 broad, ſo contrived, that the focal diſtance might be varied, and alſo the number of glaſſes, as occaſions required. In the month of March 1747, with 40 glaſſes he burnt a plank at the diſtance of about 70 feet.

If a faſcis or body of rays, which either proceeds parallel, or, by converging or diverging, reſpects a given point, do fall on the intercedent ſurface of two mediums of different refracting powers, the rays may be ſo refracted, if the ſurface be rightly formed, as to proceed parallel, or to converge to, or to diverge from, ſome other point.

Let

Let the polygonal ſurface ABCDEFG (fig. 69.) repreſent the ſurface intercedent between two mediums, the rarer being ſituated on the ſide towards R, and the denſer towards S; and let a pencil, compoſed of ſeven rays, RA, RB, RC, RD, RE, RF, RG, be incident, each ray on a different plane, as repreſented in the figure. Suppoſe the ray RA to be received on the ſurface at A, with an angle of incidence that correſponds to the angle of refraction which deflects the ray to the point S. And ſuppoſe the ray AB to be received leſs obliquely, or at a certain leſs angle of incidence; its angle of refraction will alſo be leſs, and it will proceed to S. And let a ſimilar adjuſtment of the planes at C, D, &c. be ſuppoſed, and the other rays will be refracted to the ſame point. Or if S be ſuppoſed the radiant point, the mediums being as before, the focus will be at R. It is therefore plain, that rays proceeding out of a rare into a denſe medium, are rendered more convergent by a convex ſurface, and rays, proceeding out of a denſe into a rare medium, are rendered more convergent by a concave ſurface; and the contrary.

Let

Let the pencil consist of an infinite number of rays, and the polygonal surface, which is adapted to refract it to a point, will, by reason of the infinite number of its sides, become a curve. The same argument may be applied to rays which are either convergent or parallel at their incidence on the refracting surface. Consequently, the intercedent surface of two mediums may be so formed as to refract into a focus, or render parallel, or divergent those rays, which, at their incidence are either parallel, or do, by converging or diverging, respect any particular point.

From the established laws of reflection and refraction, it is not difficult to investigate the nature of the curves, into which the before mentioned surfaces ought to be formed, which, according to circumstances, may be either the ellipsis, parabola, or hyperbola. But as the errors which arise from the use of spherical surfaces are very small, and may be remedied by other means, and the mechanical or practical construction of the above curves is very difficult, the parts of optical instruments are commonly formed spherical.

CHAP.

CHAP. II.

Of Dioptrics; or the regular Refraction of Light.

GLASS, being a medium denſer and more refracting than the air, is uſed to make the tranſparent parts of optical inſtruments which are conſtructed to act by the principle of refraction. A piece of glaſs properly figured for that purpoſe is called a lens, and is diſtinguiſhed by the nature of its ſurfaces: thus A (fig. 70.) is a plano-convex, B a double convex, C a plano-concave, D a double concave, and E a convex concave.

The two firſt lenſes, A and B, nearly reſemble each other in their properties; for they refract converging or parallel rays to a point or focus, and refract diverging rays, ſo as either to make them meet in a focus or proceed leſs divergent than before. If AB (fig. 71.) repreſent a double convex lens, and R

a radiant

a radiant point, then the rays which fall on the lens will be refracted to F, if the lens be of the requisite convexity. The two following lenses, C and D, (fig. 70.) are referred to one species, on account of the resemblance of their properties; for they render the incident rays more divergent than before, and therefore cause diverging or parallel rays to diverge from an imaginary or virtual focus, and refract converging rays, so as either to make them diverge from an imaginary focus, or proceed less convergent than before. If AB (fig. 72.) represent a double concave lens, and R a radiant point, then the rays which fall on the lens will be rendered more divergent, and will proceed as if they had emanated from the point F, which is called the virtual focus. The fifth lens E is of the nature of A and B, if its convexity be deeper, or a portion of a lesser sphere than its concavity: but if the concavity be deepest, its properties resemble those of C and D.

In the four first lenses, the changes made in the course of the rays are more considerable the more the surfaces are curved; but

in the last the changes are more considerable, the more the curvities of the two surfaces differ from each other.

A right line, as RF (fig. 71.) which passes through the center of any lens and is perpendicular to both its surfaces, is called the axis of the lens. The focus of rays which respect the axis, either by inciding parallel to it, or diverging from or converging to a point situate in it, is found in the axis, and is called the principal focus.

A right line drawn from the point of convergence or divergence of any fascis of rays incident on a lens, through the center of the lens, will pass through the focus of that fascis, if the point of convergence or divergence be not situate far from the axis.

The rays of light which diverge from the focus after passing through a lens, will occasion the sense to refer to that point, as if occupied by a lucid object; the focus, therefore, may be said to be the picture or image of the radiant point. And as a surface may be conceived to be composed of an indefinite number of radiant points, the like number of focal points will appear, and

conſequently a ſurface will be formed that will be the image of the radiant ſurface. Let OB (fig. 73.) repreſent an object, and LN a double convex lens; from O and B through C the center, draw the lines OCI and BCM, and the foci of the points O and B will be found at I and M in thoſe lines, more or leſs diſtant from C, as the curvity of the ſurfaces of the glaſs is leſs or greater. The foci of the radiant points ſituate between O and B will be found between I and M, by the ſame proceſs. Conſequently an image will be there formed, ſimilar to the object, from each point of which will diverge rays of light in the ſame manner as from a real object; and its poſition, by reaſon that the rays croſs at C, will be inverted, or contrary to the object itſelf, as appears by the figure. And becauſe the triangles OCB and ICM are ſimilar, the magnitudes of the image and the object will be to each other reſpectively as their diſtances from the lens; for,

As the ſide CO, or diſtance of the object from the lens,

Is to the ſide OB, or length of the object,

So is the ſide CI, or diſtance of the image,

To

To the ſide IM, or length of the image.

Again, let OB (fig. 74.) repreſent an object, and LN a double concave lens; draw OC and BC, and the virtual foci of the points O and B will be found at I and M in thoſe lines, more or leſs diſtant from C, as the curvity of the ſurfaces of the glaſs is leſs or greater. The intermediate points of the object will have their intermediate foci between I and M, and the poſition of the image will be erect as well as the object. And becauſe the triangles OCB and ICM are ſimilar, the magnitudes of the object and image will be as their diſtances from the lens.

Hence it may be eaſily conceived, how convex lenſes become burning-glaſſes. For, as the object and image, if viewed from the center of the lens ſubtend the ſame angle, and the Sun is ſeen under an angle of about half a degree, we may readily find the denſity of the rays which form his image in the focus of any lens. For example, if a lens, four inches broad, collect the Sun's rays into a focus, at the diſtance of one foot, or twelve inches, the image will not be more than $\frac{1}{10}$ of an inch broad.

The ſurface of this little circle, therefore, will be 1600 times leſs than the ſurface of the lens, and conſequently the Sun's light muſt be ſo many times denſer within that circle. No wonder, then, that it burns with a degree of violence and ardor far exceeding that of any culinary fire.

If a paper or white ſubſtance be held in the focus of a convex lens, the ſeveral foci of the radiant points of objects ſituated on the other ſide of the lens will illuminate as many points on the paper; which illuminated points agreeing in relative ſituation, intenſity, and colour with thoſe of the objects themſelves, will depict an exact and lively perſpective view of the ſame, but which, by reaſon of the croſſing of the rays, will be inverted. But this phenomenon is ſcarcely to be ſeen, if any light be permitted to fall on the paper beſides that which paſſes through the lens; for which purpoſe the lens may be fixed in the window-ſhutter of a darkened chamber, as we ſhall have occaſion to remark in future.

CHAP.

CHAP. III.

Of the Eye; and of Vision.

IF the whole frame of the univerſe were not ſo evident a proof of the exiſtence of a ſupremely wiſe and benevolent Creator, as to render particular arguments unneceſſary, the ſtructure of the eye might be offered as one, by no means of the leaſt; for it poſſeſſes all the conveniencies of the moſt perfect optical inſtruments without their imperfections. This inſtance, among numberleſs others, demonſtrates, that the beſt performances of art are infinitely ſhort of thoſe which are hourly produced by the divine mechanic.

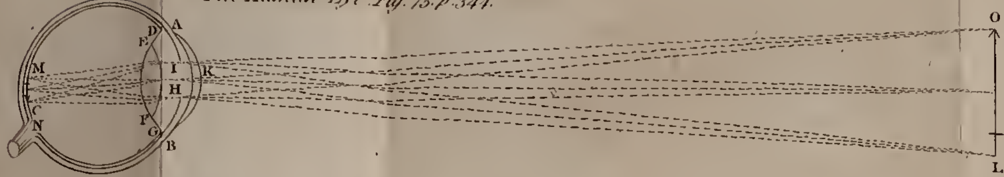
Though the apparatus, by which the eye is preſerved and kept in a ſtate proper for the quick motion and accurate direction towards the object to be viewed, is well worth attention and remark; yet, as it does not immediately come under our notice as illuſtrative of the principles of optics, we ſhall wave it, and conſider only the globe of the eye, or organ by which viſion is performed.

The eye is composed of several tunics or integuments, one within the other, and is filled within with transparent humors of different refractive densities. The external tunic is called the sclerotica, and is white on the anterior part of the eye, except a circular part immediately in front, which is transparent, and more convex than the rest of the eye: this transparent part is called the cornea. Immediately adherent to the sclerotica within is the choroides, or uvea, which, at the circumference of the cornea, becomes the iris, being expanded over great part of its surface, though not contiguous to it. The iris is composed of two kinds of muscular fibres; the one sort tend like the radii of a circle towards its center, and the others form a number of concentric circles round the same center. The central part of the iris is perforated, and the orifice, which is called the pupil, is of no constant magnitude; for, when a very luminous object is viewed, the circular fibres of the iris contract, and diminish its orifice; and on the other hand, when objects are dark and obscure, the radial fibres of the iris contract, and enlarge the pupil so as to admit a greater

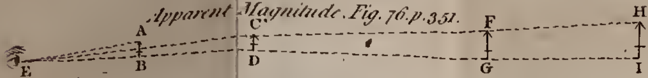
to face p. 343. Vol. I.

N°. XVII.

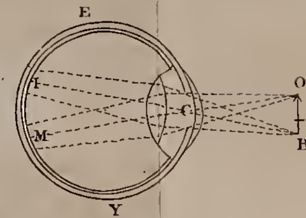
The Human Eye. Fig. 75. p. 344.



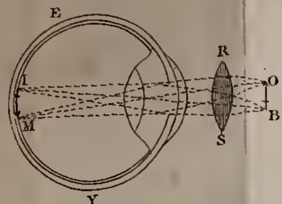
Apparent Magnitude. Fig. 76. p. 351.



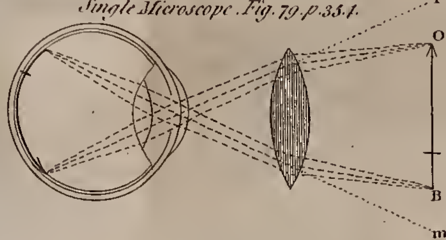
Vision. Fig. 77. p. 352.



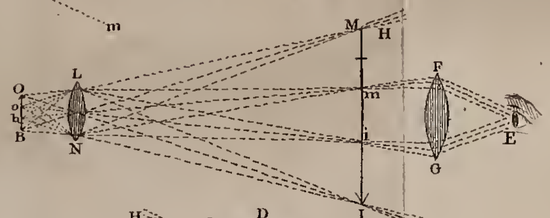
Single Microscope. Fig. 78. p. 352.



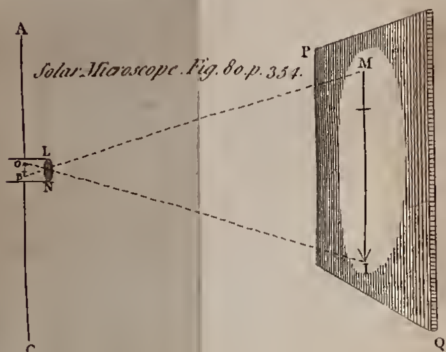
Single Microscope. Fig. 79. p. 354.

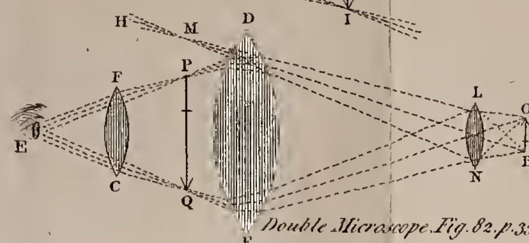


Double Microscope. Fig. 81. p. 355.



Solar Microscope. Fig. 80. p. 354.





Double Microscope. Fig. 82. p. 357.

quantity of light into the eye. The iris is variouſly coloured in different perſons, but according to no certain rule: in general, people whoſe hair and complexion are light coloured, have the iris blue or grey; and on the contrary, thoſe whoſe hair and complexion are dark, have the iris of a deep brown. But what ſpecific difference this may occaſion in the ſenſe, or whether any at all, is not diſcoverable. Within the uvea is another membrane, which at the circumference of the cornea becomes fibrous, and is called the ligamentum ciliare. This ligament is attached to the circumference of a double convex lens, whoſe axis correſponds with the center of the pupil; and which, by means of the fibres, can be altered in a ſmall degree in poſition, and perhaps in figure. The lens is termed the cryſtalline humor; and is included in a very ſtrong and tranſparent membrane, called the arachnoides. Between the cryſtalline humor and the cornea is contained a clear tranſparent fluid, which is called the aqueous humor; and between the cryſtalline humor and the poſterior part or bottom of the eye is ncluded another clear tranſparent fluid, which

is termed the vitreous humor. The refractive denſity of the cryſtalline is greater than thoſe of the humors by which it is ſurrounded. On the ſide next to the noſe a nerve is inſerted in the bottom of each eye, about twenty-five degrees from the axis of the cryſtalline, which, after entering the eye, is ſpread into an exceeding fine coat of network, termed the retina. Laſtly; a very black mucus or ſlime is ſpread over all the internal parts of the eye, which are not tranſparent, except the anterior part of the iris, which, as before obſerved, is coloured.

In the figure, the three concentric circles ABC (fig. 75.) repreſent the coats of the eye. The external coat, or ſclerotica, is tranſparent, and more convex between A and B, AKB being the cornea. The ſecond tunic, or uvea, is fibrous between D and I, and between G and H, and is there called the iris; the hole IH is the pupil. The third coat becomes fibrous between D and E, and between G and F, being there called the ligamentum ciliare, and is attached to the circumference of the lens or cryſtalline humor EF. The

cavity

cavity or chamber AEFB is filled with the aqueous humor, and the chamber DNGFE is filled with the vitreous humor. At N is inſerted the optic nerve, the expanſion of which, over the internal ſurface DNG, is the retina.

The manner in which the eye acts upon the rays of light may be thus explained. Let OL repreſent an object, and ſuppoſe a pencil of light to emanate from O, and enter the eye; then, becauſe the cornea is a convex concave lens, whoſe convexity is greateſt, the rays will be rendered more convergent in paſſing through it; and if the cryſtalline be properly formed, they will be refracted by it into a focus at C on the retina. The ſame will happen to the pencil which emanates from L, whoſe focus will be M; and the foci of the intermediate points will be between M and C: conſequently an inverted picture or image will be formed on the retina, and ſenſation be produced by the action of the light on the expanſion of the optic nerve, which from thence is conveyed to the ſenſorium. And that the parts of the eye are adapted to produce ſuch an image, appears likewiſe from experiment: for if the tunica ſclerotica be

carefully

carefully taken away from the back of the eye of any animal, the inverted picture of external objects may be seen on the thin membranes which remain: neither is the inversion of the image any obstacle to the mind's conceiving that the object is erect; for a focus at M may be considered as the indication of the existence of a radiant point at L, and a focus at C may indicate the existence of a radiant point at O; and so of others, the mind contemplating the object itself, and not the image; besides which, we have notions respecting position which are not derived from the sight, by which we judge whether a wall is perpendicular or a plane level, &c. These notions are derived from a perception of the direction in which gravity constantly acts; to which direction we always refer. Whence it happens, that though the position of the eye be ever so much changed, the idea of the position of objects in view remains unchanged. For example; if a man view an upright pole or staff, the image of the pole on the retina will be in a line at right angles to the opening of the eyelids, provided he holds his head upright; but if he vary the position of his head,

head, the image will be formed in a different poſition, and upon a different part of the retina: notwithſtanding which, he conſtantly imagines the pole to be erect and unaltered.

Becauſe the foci of rays that differ in divergence are found at different diſtances from the lens, thoſe which diverge leſs coming to a focus ſooner than thoſe which diverge more, it is neceſſary that the eye ſhould be adapted ſo as to act upon the rays which arrive from points at various diſtances, and to bring them to a focus upon the retina. The natural ſtructure of the eye is ſuch, that parallel rays have their focus on the retina; and when the proximity of any object cauſes its rays to fall with a greater divergency, the pupil of the eye contracts and excludes the moſt divergent rays, at the ſame time that the cryſtalline is brought forward, and perhaps rendered more convex by means of the ligamentum ciliare, by which proviſions the focus ſtill falls on the retina. This adjuſtment of the eye to the diſtances of objects gives the reaſon why we cannot view a near and a diſtant object at the ſame time; for, if a hair be held at a few inches diſtance between the eye and a remote object,

object, ſuppoſe a man at half a mile diſtance, the man will appear confuſed and indiſtinct when the attention is fixed on the hair, and the ſame will be the caſe with the hair when the attention is fixed on the man.

There are ſome eyes naturally ſo defective, that they cannot effect this adjuſtment. Thoſe which are replete with humors have the cornea and cryſtalline too convex, by which means the pencils come to their foci before their arrival at the retina, on which they fall in ſmall circular ſpaces inſtead of points, and by their interference render the image confuſed; on the other hand, if the humors be deficient in quantity, the cornea and cryſtalline are too flat, and the pencils of rays not being ſufficiently refracted, arrive at the retina before their union in their foci; whence ariſes the ſame confuſion in the image as in the former caſe. They whoſe eyes are imperfect in the firſt manner are called myopes, from their winking or cloſing their eye-lids, but more commonly *near-ſighted*, becauſe they ſee very near objects diſtinctly, the divergency of the rays cauſing their foci to fall on the retina. They whoſe eyes are too flat are called preſ-

bytæ,

bytæ, becaufe the imperfection of the fight of old men is generally of this kind, it being occafioned by a decay of the humors. Both thefe imperfections may in a great meafure be remedied by the ufe of proper fpectacles. Since the rays converge too foon in the eyes of myopes, it is plain that a concave lens interpofed between the object and the eye will caufe the rays to fall more divergent, and confequently will prevent their converging to a focus before their arrival at the retina. And the rays may be made to converge fooner in the eyes of prefbytæ, by means of convex fpectacles, by which they, being already convergent when they enter the eye, will be fufficiently refracted by the cornea and cryftalline to have their focus on the retina, and caufe diftinct vifion.

The eyes of various animals are accommodated with great fkill to the exigences of their fituations. In fifhes the cornea is almoft flat, that it may be no obftacle to their fpeed in the water, but this is compenfated by the cryftalline, which is fpherical, and therefore adapted to perform the whole neceffary refraction of the rays. And in cats and fome other

other animals that prey in the dark, the pupil of the eye is ſo variable as to admit more than an hundred times the quantity of light at one time than another. The human eye admits more than ten times the quantity of light at one time than at another, and perhaps the differences may be much greater in very dark places: it is not impoſſible but that the iris may be then almoſt intirely drawn back, and the pupil expand to the whole ſurface of the cornea.

C H A P. IV.

Of refracting Microſcopes; or the Dioptric Inſtruments, by Means of which ſmall and near Objects are ſeen magnified.

THE apparent magnitude of any object is meaſured by the angle under which it is viewed by the eye; conſequently the apparent magnitudes of two or more objects may be the ſame, or may differ in any proportion, let their real magnitudes be what they will. Thus, the apparent magnitudes of CD, FG,

FG, and HI, (fig. 76.) are equal when viewed by the eye at E, becauſe they are ſeen under the ſame angle, though their real magnitudes are very different: and the apparent magnitude of AB is greater than thoſe of the former three, becauſe it ſubtends a greater angle, though its real magnitude is equal to that of CD, and leſs than thoſe of FG and HI.

The image of any object on the retina, will be greater or leſs in proportion to its apparent magnitude, and therefore the ſame object is ſeen more enlarged and diſtinct the nearer it is brought to the eye, provided its diſtance be ſufficiently great for the rays to fall nearly parallel on the pupil: at leſs diſtances it continues to be enlarged, but is confuſed. The leaſt diſtance is about ſix inches. The eye can juſt diſtinguiſh objects which ſubtend an angle of * half a minute of a degree, in which caſe the image on the retina is leſs than the $\frac{1}{7200}$ part of an inch broad, and the object, ſuppoſing it ſix inches diſtant, about the $\frac{1}{1200}$ part of an inch broad. And

* Obſervations taken by the naked eye with Hadley's quadrant may be depended on to the exactneſs of half a minute.

all

all ſmaller objects are inviſible to the naked eye.

The inſtruments by which thoſe ſmaller objects are rendered viſible are called microſcopes, and are conſtructed upon a twofold principle. The one is, by the interpoſition of a convex lens between the object and the eye, to render it diſtinct at a leſs diſtance than ſix inches, by which means its apparent magnitude increaſes as the diſtance is diminiſhed: and the other is by placing the object ſo with reſpect to a convex lens that its focal image may be much greater than itſelf, and contemplating that image inſtead of the object. The firſt are called ſimple or ſingle microſcopes, and the latter compound or double.

Let EY (fig. 77.) repreſent the eye, and OB a ſmall object, ſituate very near, ſo that the angle of its apparent magnitude OCB may be large. Then its image on the retina IM will alſo be large; but becauſe the pencils of rays are too divergent to be collected into their foci on the retina, it will be very confuſed and indiſtinct. Let the convex lens RS (fig. 78.) be interpoſed, ſo that the diſtance between

between it and the object may be equal to the focal length at which parallel rays would unite, and the rays which diverge from the object and paſs through the lens will afterwards proceed, and conſequently enter the eye parallel: they will therefore unite, and form a diſtinct image on the retina, and the object will be clearly ſeen; though if removed to the diſtance of ſix inches, its ſmallneſs would render it inviſible. And ſince the apparent magnitudes of objects that ſubtend ſmall angles are nearly in the inverſe proportion of their diſtances, if the real magnitudes be equal, the proportion in which the object is magnified will be as ſix inches to its diſtance from the eye. Whence it follows, that the moſt convex lenſes, having the ſhorteſt focal diſtance of parallel rays, do magnify the moſt; for they permit the object to approach nearer the eye than thoſe do which are flatter. When the lens is not held cloſe to the eye, the object is amplified ſomewhat more; becauſe the pencils, which paſs at a diſtance from the center of the lens, are refracted inwards toward the axis, and conſequently ſeem to come from points more remote from the

center of the object, as may be ſeen in fig. 79. where the pencils which emanate from O and B, are refracted inwards, and ſeem to come from the points i and m.

A drop of water is a microſcope of this kind, by reaſon of its convex ſurface; for, if a ſmall hole be made in a plate of metal, or other thin ſubſtance, and carefully filled with a drop of water, ſmall objects may be ſeen thro' it very diſtinct, and much magnified. But there are ſome difficulties in the management of theſe, which ſmall glaſſes are free from, and therefore they are not much uſed. In fact, cheapneſs is their principal recommendation.

The compound microſcope, by means of which the image is contemplated inſtead of the object, is of two kinds, the ſolar and the common double microſcope. The ſolar microſcope is thus conſtructed: let AC (fig. 80.) repreſent the ſide of a darkened chamber, LN a convex lens, fixed oppoſite a perforation in AC, OB a ſmall object, and PQ a white ſcreen placed within the chamber oppoſite to the lens; then, if the object be placed at a due diſtance from the lens, the pencil of

light

light which proceeds from the point O will converge to a focus on the ſcreen at I, and the pencil which proceeds from the point B will converge to a focus at M, and the intermediate points of the object will be depicted between I and M, forming a picture which will be as much larger than the object in proportion as the diſtance of the ſcreen exceeds that of the image from the lens. This is the principle on which the inſtrument acts, but it is uſual to add other auxiliary parts as a lens or ſpeculum to illuminate the object by converging the Sun's light upon it, &c. which our limits do not permit us to enlarge upon. The ſolar miſcroſcope is by far the moſt pleaſing in its effects, and leaſt offenſive to the eyes of any in uſe.

In the common double miſcroſcope the image is contemplated inſtead of the object, being viewed through a ſingle lens in the ſame manner as the object in a ſingle microſcope. Thus,

Let LN (fig. 81.) repreſent a double convex lens, and OB a ſmall object, ſo applied, that the pencils of rays which emerge from it, and paſs through the lens, may converge

to their reſpective foci, and form an inverted image at IM. This image will be as much larger than the object in proportion as its diſtance exceeds that of the object from the lens, and, if it be viewed through the lens FG, will again be magnified upon the principle of the ſingle microſcope, in proportion as its diſtance from the eye is leſs than ſix inches; the image formed by the firſt lens, which is called the object-glaſs, ſerving inſtead of an object for the ſecond, or eye-glaſs. But it is to be noted, that the image formed in the focus of a lens differs from the real object in a very eſſential particular; that is to ſay, the light being emitted from the object in every direction, renders it viſible to an eye placed in any poſition, but the points of the image formed by a lens or mirror emitting no more than a ſmall conical body of rays, which arrives from the glaſs, can be viſible only when the eye is ſituate within its confine. Thus, the pencil which emanates from B in the object, and is converged by the lens to M, proceeds afterwards diverging towards H, and therefore never arrives at the lens FG, nor enters the eye at E. But the pencils which

proceed

proceed from the points o and b will be received on the lens FG, and by it carried, parallel, to the eye; consequently the correspondent points of the image i and m will be visible, and those which are situate farther out towards I and M will not be seen. This quantity of the image i m, or visible area, is called the field of view.

Hence it appears, that if the image IM be large, a very small part of it will be visible, because the pencils of rays will for the most part fall without the eye-glass FG. And it is likewise plain, that a remedy which would cause the pencils, which proceed from the extremes O and B of the object, to arrive at the eye will render a greater part of it visible; or, in other words, enlarge the field view. This is effected by the interposition of a broad lens DE (fig. 82.) of a proper curvature at a small distance from the focal image. For, by that means the pencil BM, which would otherwise have proceeded towards H, is refracted to the eye, as delineated in the figure, and the mind conceives from thence the existence of a radiant point at P,

 from

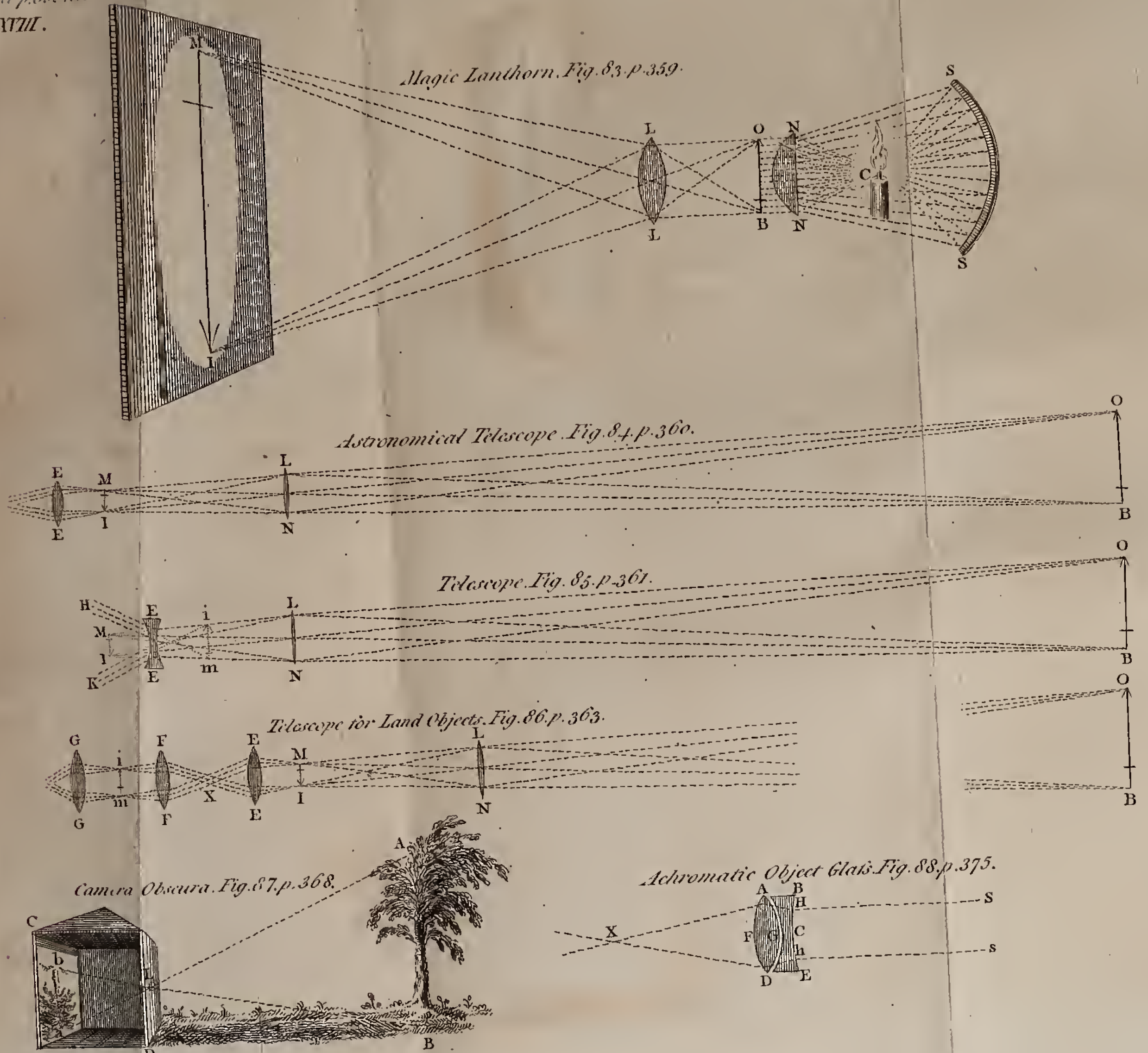
from which the rays laſt proceeded. In like manner, and by a parity of reaſon, the other extreme of the image is ſeen at Q, and the intermediate points are alſo rendered viſible. On theſe conſiderations it is, that compound portable microſcopes are uſually made to conſiſt of an object lens, LN, by which the image is formed, enlarged, and inverted, an amplifying lens, DE, by which the field of view is enlarged, and an eye-glaſs or lens, by means of which the eye is allowed to approach very near, and conſequently to view the image under a very great angle of apparent magnitude.

The magic lanthorn is a microſcope upon the ſame principles as the ſolar microſcope, and may be uſed with good effect for magnifying ſmall tranſparent objects; but in general it is adapted for the purpoſe of amuſement, by caſting the ſpecies or image of a ſmall tranſparent painting on glaſs upon a white wall or ſcreen, at the focal diſtance from the inſtrument. After what has already been ſaid, it will be eaſy to underſtand the following deſcription of its component parts.

In

[illegible] p. 359. Vol. 1.

No XVIII.



In the inſide of a box or lanthorn is placed the candle or lamp C, (fig. 83.) the light of which paſſes through the plano-convex lens NN, and ſtrongly illuminates the object OB, which is a tranſparent painting on glaſs, inverted and moveable before NN, by means of a ſliding piece in which the glaſs is ſet or fixed. This illumination is ſtill more increaſed by the reflection of light from a concave mirror, SS, placed at the other end of the box, which converges the light upon the lens NN, as repreſented in the figure. Laſtly, a lens LL, fixed in a ſliding tube, is brought to the requiſite diſtance from the object OB, and a large erect image IM is formed upon the oppoſite wall.

CHAP. V.

Of refracting Telescopes; or the dioptric Instruments, by Means of which remote Objects are rendered large and distinct to the View.

AS the microſcope is calculated to obviate the defects of viſion with regard to objects, whoſe angles of apparent magnitude are too ſmall for ſight on account of the ſmallneſs of the objects themſelves, ſo teleſcopes are adapted to improve the ſenſe with reſpect to objects, whoſe angles of apparent magnitude are too ſmall for ſight by reaſon of their remoteneſs or diſtance. The intention of both inſtruments is the ſame, namely, to increaſe that angle, and, by conſequence, the teleſcope differs very little from the compound microſcope, except in ſome particulars of convenience.

Let LN (fig. 84.) repreſent a convex lens, and OB a diſtant object; then the pencils of rays will be collected into their reſpective

tive foci, and form the inverted image IM, to which the eye, by means of the lens EE, may approach ſo near as to view it very large and diſtinct. This is the common aſtronomical teleſcope.

But, as it is inconvenient to view objects on the earth inverted, there are uſually contrivances annexed to the teleſcope by which the image becomes erect as well as the object. The ſimpleſt of theſe is the following, where a concave is ſubſtituted inſtead of the convex eye-glaſs.

Let LN (fig. 85.) repreſent the object-glaſs as before, and OB a diſtant object. Then the pencils from the reſpective points of the object would converge to their foci, and form the inverted image IM, if the lens EE were not interpoſed. But the lens EE being a double concave, occaſions the rays to diverge more than before; ſo that the rays which emanate from B in the object, inſtead of converging to M, are made to proceed parallel towards H. On the ſame ground the rays from O are made to proceed parallel towards K. And in like manner are the intermediate pencils affected. Now, ſince

parallel rays cauſe diſtinct viſion, it is plain, that an eye placed in the pencil H, will conceive it to emanate from ſome point, ſuppoſe m, ſituate in the laſt direction of the rays, and the image of B will be ſeen at m. By the ſame argument, the image of O will be ſeen at i, by an eye ſituated at K, and the like for the intermediate points. Therefore, an image will be ſeen at i m, erect or ſimilarly ſituated with the object itſelf.

This teleſcope repreſents objects very bright and clear, and as much magnified as does the other, but it is unpleaſant in its uſe, by reaſon of its contracted field of view. For the pencils, being rendered divergent with reſpect to each other, do, for the moſt part, paſs on one or the other ſide, without entering the pupil of the eye, and therefore a very ſmall part of the image can be ſeen at once: thus if the eye be at H, it will view the point m, and if it be moved towards K, it will ſee in ſucceſſion all the parts of the image towards i: but, as the pupil of the eye is not broad enough to receive the pencils H and K at the ſame time, the points m and i cannot be ſeen at once. The larger the pupil and the nearer it is

placed

placed to the eye-glaſs, the more pencils enter the eye at once. Conſequently the field of view is largeſt under theſe circumſtances, and in all other caſes leſs.

By the addition of two eye-glaſſes to the aſtronomical teleſcope, it is adapted to terreſtrial objects, the field of view remaining the ſame. Thus the lens FF (fig. 86.) which is ſimilar to EE, being placed at twice the focal diſtance for parallel rays from EE, receives the pencils of parallel rays after they have croſſed each other at X, and forms an image at i m, ſimilar and equal to IM, but contrary in poſition, or erect, which laſt image is viewed by the lens GG. This is the common teleſcope, and though, by reaſon of the number of lenſes, it does not repreſent objects ſo bright as the foregoing, yet its ample field of view makes it much more pleaſing and uſeful.

It has been before obſerved, that the opacity of bodies ariſes from the largeneſs of their interſtices or pores, which contain mediums of different denſities from the particles of the body. Hence it is that ſeveral tranſparent fluids become opake when mixed

ed with others, equally tranſparent, but of different refractive denſities; and from this cauſe it ariſes, that the atmoſphere is never perfectly tranſparent, though more ſo at ſome times than at others. The following obſervation may perhaps ſerve to illuſtrate this matter. If a ſmall quantity of ſpirits of wine be poured into a glaſs of water, the mixture becomes much leſs tranſparent than before; the ſpirits remaining for a conſiderable time in the form of veins or waves, on account of the imperfect mixture; but when the two liquors are more intimately united, the tranſparency is reſtored. The opacity ariſes from the multitude of reflections at the common ſurfaces of the veins of ſpirits and water: and the tranſparency is reſtored when thoſe veins, by mixture, are become too ſmall to reflect; for then the light is intirely tranſmitted. In the ſame manner the exhalations which continually riſe from the Earth, render the air leſs tranſparent, eſpecially near the Earth, where the mixture is leſs complete, and therefore the celeſtial bodies are ſeen much more obſcure when in the horizon than when at any conſiderable elevation; for

in

in the firſt caſe, they are viewed through that part of the atmoſphere which is contiguous to the ſurface of the Earth, and in the latter through a part which is at a greater diſtance. But this obſcurity is the leaſt part of the inconvenience. The riſing exhalations have a kind of undulating motion, like that of ſmoke or ſteam, ſo that objects ſeen through them appear to have a tremulous or dancing motion, which is ſenſible even to the naked eye, if diſtant objects be viewed in a ſummer's day over an intervening marſh or bog. In teleſcopes this effect is ſtill more perceptible, inſomuch as to render them intirely uſeleſs, for terreſtrial objects, when they augment the apparent magnitude more than eighty times. But when objects in the heavens are viewed at any conſiderable altitude, inſtruments may be uſed which magnify more than two hundred times.

From this want of tranſparency in the atmoſphere ariſes that gradual diminution in the light of objects, which painters call the aerial perſpective; for, if the air were perfectly tranſparent, an object would be equally luminous at all diſtances, becauſe the viſible area

and

and the denſity of light decreaſe in the ſame proportion, namely, as the ſquare of the diſtance. It is from this gradual diminution of light, together with the angle of apparent magnitude, that we eſtimate diſtances; and becauſe the celeſtial bodies, when near the horizon, are more obſcure, for the reaſon urged above, though their reſpective apparent magnitudes remain unaltered, or in a ſmall degree diminiſhed, we adopt the notion of their being actually larger at that time. Thus, likewiſe, men ſeen through a miſt appear gigantic, the obſcurity cauſing us to imagine them more diſtant than they really are. But, in the caſe of the heavenly bodies, there is another circumſtance that tends to deceive us in our judgment of the diſtance: we conceive the ſky to be a concave dome; and as the clouds towards the horizon are evidently more diſtant than thoſe near the zenith, we imagine the horizontal radius to be much longer than the vertical. From this notion we regulate our ideas with regard to the diſtance of the heavenly bodies at different altitudes; which diſtance, we ſuppoſe to be greater when they are nearer the hori-

 zon,

zon, and we are conſequently led to imagine, that they are larger at that time.

The air reflects the blue rays moſt plentifully, and muſt therefore tranſmit the red, orange and yellow, more copiouſly than the other rays. If the light of the ſetting Sun, by paſſing through a long tract of air, be diveſted of the more reflexible rays, the green, blue, indigo, and violet, the remainder, which is tranſmitted, will illuminate the weſtern clouds with an orange color; and as the Sun ſets more and more, the tract of air, through which the rays muſt paſs, becomes longer, the yellow and orange are reflected, and the clouds grow more deeply red, till at length the diſappearance of the Sun leaves them of a leaden hue, by the reflection of the blue light from the air. A ſimilar change of colour has been obſerved near ſun-ſet on the ſnowy tops of the Alps in Switzerland.

The undulating motion of the vapours in the air is very perceptible in the twinkling of the ſtars, and in the tremulous motion with which the ſhadows of lofty buildings are agitated.

By

By the ſolar microſcope and magic lanthorn, we have ſeen that the ſpecies of near objects may be caſt on a ſcreen in a darkened chamber. The camera obſcura has the ſame relation to the teleſcope, as the ſolar microſcope has to the common double microſcope, and is thus conſtructed.

Let CD (fig. 87.) repreſent a darkened chamber perforated at L, where a convex lens is fixed, the curvity of which is ſuch, that the focus of parallel rays falls upon the oppoſite wall. Then, if AB be an object at ſuch a diſtance, that the rays which proceed from any given point of its ſurface to the lens L, may be eſteemed parallel, an inverted picture will be formed on the oppoſite wall. For the pencil which proceeds from A will converge to a, and the pencil which proceeds from B, will converge to b, and the intermediate points of the object will be depicted between a and b. This is one of the moſt pleaſing and delightful experiments in optics, and never fails to ſtrike the beholder with ſurpriſe and admiration. Which indeed is not to be wondered at, for if there be any pleaſure in contemplating a well executed painting, how much

much more forcibly muſt the attention be fixed when the painting is drawn by the unerring hand of nature? When, to a perſpective the moſt minutely exact, the ſofteſt tints and the moſt animated colouring, is added the inimitable perfection of life and motion! The only defect is the inverted poſition of the picture, which may be remedied by ſeveral methods. But as they all tend to make the image leſs lively, they are ſeldom uſed.

C H A P. VI.

Of the Imperfections of Teleſcopes, and their Remedies; and of the achromatic Teleſcope.

SINCE the conſtruction of a teleſcope conſiſts in nothing more than viewing, by means of a microſcope or eye-glaſs, the image which is formed in the focus of the object-glaſs; it may ſeem eaſy to make a teleſcope with a given object-glaſs, that ſhall magnify in any aſſignable degree. For, if the eye-glaſs be rendered more and more convex, the eye may be permitted to approach nearer

and nearer to the image, and consequently to view it under an angle of apparent magnitude that ſhall be greater and greater, as required. But this is unattainable on two ſeveral accounts. The firſt is, that ſpherical ſurfaces do not refract the rays of light accurately to a point, as has already been obſerved; and the ſecond and moſt conſequential is, that the rays of compounded light, being differently refrangible, come to their reſpective foci at different diſtances from the glaſs, the more refrangible rays converging ſooner than thoſe which are leſs refrangible. This is evident from what has already been ſaid on that ſubject, and is likewiſe confirmed by experiment; for a paper, painted intenſely red, and properly illuminated, will caſt its ſpecies, by means of a lens, on a ſcreen at a greater diſtance than will another blue paper by the ſame lens in like circumſtances. And here it may be noted, that the lens proper for this experiment muſt be very flat, or a portion of the ſurface of a large ſphere. Hence the ſpecies or image of a white object may be ſaid to conſiſt of an indefinite number of coloured images, the violet being

neareſt,

neareſt, and the red fartheſt from the lens, and the images of intermediate colours at intermediate diſtances. The aggregate, or image itſelf, muſt therefore be in ſome degree confuſed, and this confuſion, being very much increaſed by the magnifying power, or eye-glaſs, renders it neceſſary to uſe an eye glaſs of a certain limited convexity to a given object-glaſs. For which reaſon, if it be required to conſtruct a teleſcope that ſhall magnify objects in a greater degree than a given teleſcope, the object-glaſs muſt be leſs convex, and of conſequence its focal diſtance longer. Thus an object-glaſs of 4 feet focal length will bear an eye-glaſs of about $1\frac{1}{5}$ inch focus, and will magnify objects in length or diameter 40 times: one of 25 feet focal length will bear an eye-glaſs of 3 inches focus, and magnifies 100 times: and one of 100 feet will bear an eye-glaſs of ſix inches, and magnifies 200 times. It is alſo neceſſary to limit the aperture of the object-glaſs, to exclude thoſe rays which are incident at too great diſtances from the center; for thoſe, being more refracted, are more particularly ſubject to the irregularities which ariſe,

either from the figure of the glaſs or the unequal refraction of light. The diameter of the apertures of object lenſes ſhould be as the ſquare roots of their focal lengths.

The great inconvenience and difficulty of managing the longer teleſcopes, occaſioned the philoſophic world to fix their thoughts upon the means of converging the rays of light without ſeparating them into their component colours. The expedients for that purpoſe were firſt perfected by Sir Iſaac Newton and Mr. Dollond. The focal image in the teleſcope of Sir Iſaac Newton is formed by reflection from ſpeculums or mirrors, and being therefore free from the irregular convergency of the various rays of light, will admit of a much larger aperture, and bear the application of a very great magnifying power. The difficulties which attend this inſtrument, are the tarniſhing of the metalline ſpeculums, and the very great accuracy required in giving them the true figure, for an error in a reflecting ſurface affects the direction of the rays much more than a like error in a refracting ſurface. Yet this teleſcope is, notwithſtanding, the

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beſt in uſe. Mr. Dollond's invention conſiſts in the uſe of a compound object-glaſs, which is uſually termed achromatic, or colourleſs, from its property; and the principal imperfection in the practice, is the difficulty of procuring glaſs that ſhall be uniformly of the ſame refractive denſity. As we are now ſpeaking of dioptrics, it will be more regular to deſcribe the achromatic teleſcope firſt, and refer the other to its place, where we ſhall explain the properties of inſtruments that act on the principle of reflection.

Becauſe the component rays of light differ from each other in refrangibility, they are ſeparated from each other by refraction, and becauſe they are all refracted ſo as to preſerve a conſtant ratio between the ſines of the angles of incidence and refraction, that ſeparation muſt be greateſt when the whole beam of light is moſt deflected from its courſe. From hence opticians have concluded, and there is a paſſage in Sir Iſaac Newton's * optics, that ſeems to confirm the

* Book I. Part 2. Experiment VIII.

opinion, that prifms, which deflect the whole beam of light equally out of its courfe at like incidences, will, however different their refractive denfities, occafion alfo an equal feparation or divergency of the component rays: or, in other words, that if the emergent refracted light from the furface of a given prifm be received on the furface of a fecond prifm, which fhall refract it equally in the contrary direction, fo that at its emergence, it fhall proceed parallel to the firft incident beam, this laft emergent light will continue white, however different the matter of the fecond prifm may be from that of the firft. But this Mr. Dollond has fhewn to be ill-founded, for, by his experiments it appears, that the different kinds of glafs differ extremely with refpect to the divergency of colours produced by equal refractions. He found that two prifms, one of white-flint-glafs, whofe refracting angle was about 25 degrees, and another of crown-glafs, whofe refracting angle was about 29 degrees, refracted the beam of light nearly alike, but that the divergency of colour in the white-flint was confiderably

ably more than in the crown-glaſs; ſo that, when they were applied together, to refract contrary ways, and a beam of light tranſmitted through them, though the emergent continued parallel to the incident part, it was, notwithſtanding, ſeparated into the component colours. Whence he inferred, that, in order to render the emergent beam white, it was neceſſary that the refracting angle of the priſm of crown-glaſs ſhould be increaſed; and by repeated experiments, he diſcovered the exact quantity. But this colourleſs emergent light was not then, by reaſon of the increaſed angle of the priſm of crown-glaſs, parallel to the incident ray, but was refracted towards the baſe of the laſt mentioned priſm.

By theſe means he obtained a theory, in which refraction was performed without any ſeparation or divergency of colour, and which it was not difficult to apply in the conſtruction of the object-glaſſes of teleſcopes. Let ABED (fig. 88.) repreſent a double concave lens of white-flint-glaſs, and AGDF a double concave of crown-glaſs; then the parts of the lenſes which are on the ſame ſide

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of the common axis, namely, ACB and AFG, may be conceived to act like two prisms, which refract contrary ways, and if the excess of refraction in the crown-glass AFG be such as precisely to destroy the divergency of colour caused by the flint-glass ACB, the incident ray SH, will be refracted to X, without any production of colour. The same is also true of the ray s h, and of all the other incident rays, and consequently the whole focal image formed by this compound object-glass will be achromatic, or free from colour which might arise from refraction. It will therefore bear a larger aperture and greater magnifying power, and of course enlarge objects much more than a common refracting telescope of the same length.

It is more convenient on several accounts, especially in the shorter telescopes, to combine three lenses together, one double concave of flint-glass between two convexes of different kinds of crown-glass.

In the construction of this and all other instruments, there are difficulties occur in the practice, the remedies for which are well known to

to ingenions workmen, and may be gathered from the perusal of authors who have written expresly on the subject. But we omit them, as not so immediately tending to our purpose, which is chiefly theoretic.

CHAP. VII.

Of Catoptrics, or the regular Reflection of Light; and of the Reflecting Telescope.

IT has been shewn, that a surface may be constructed that shall reflect the rays of a given pencil of light, so as to make them either converge to a point, diverge from a point, or proceed parallel to each other. This surface may be either plane or curved.

A plane mirror reflects a pencil of light under the same circumstances as it was incident; that is to say, if a pencil, which emanates from a given point, be incident on the mirror, it is reflected so, that its rays proceed with the same divergency from another point, whose distance behind the mirror is equal to the distance of the radiant point before

ſore the mirror from the place of incidence: and if the pencils of rays, which emanate from a given ſurface, be incident on the mirror, they will be reflected ſo as to preſerve the ſame inclinations to each other as before, and therefore will appear to proceed from a ſurface, whoſe magnitude and diſtance behind the mirror are exactly equal to thoſe of the radiant ſurface. Hence it is, that plane mirrors reflect the ſpecies of objects, which are equal, like, and ſimilar in poſition with the objects themſelves.

Concave mirrors render the pencils of rays, which are incident upon them, more convergent, and convex mirrors render them more divergent. If the mirrors be regularly formed, according to the proper curve, the convergent or divergent light will reſpect ſome particular point of ſpace.

The diſk or part of a ſphere, whoſe breadth is about fifteen degrees, differs inſenſibly from the curve, by which parallel rays would be made by reflection to converge to, or diverge from, a point, and is therefore uſed for that purpoſe, as being much eaſier to conſtruct.

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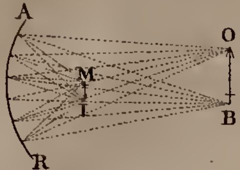
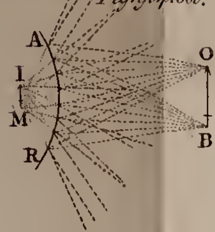
to face p.379. Vol. I.

No. XIX.

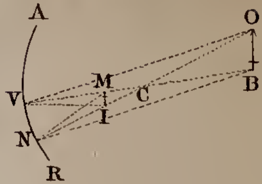
Concave mirror Fig. 89. p. 379.



Convex mirror Fig. 90. p. 380.

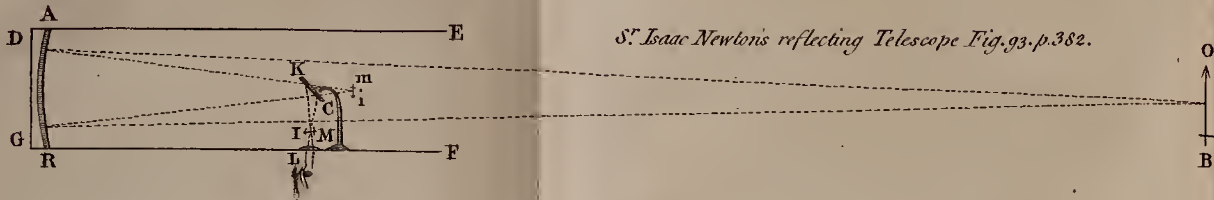


Concave mirror Fig. 91. p. 381.

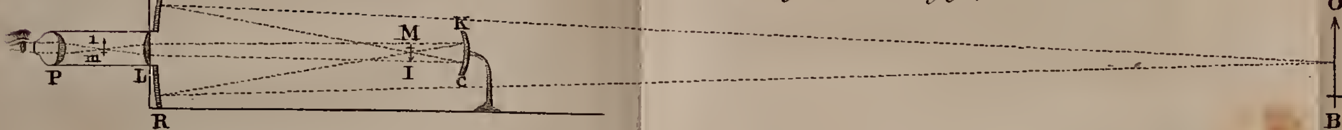


Convex mirror Fig. 92. p. 381.

S^r Isaac Newton's reflecting Telescope Fig. 93. p. 382.



Reflecting Telescope Fig. 94. p. 383.



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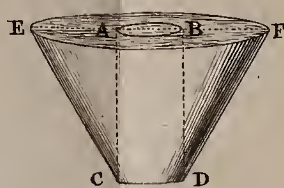
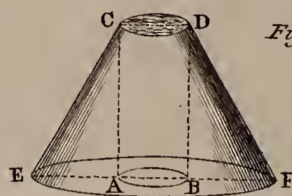
Presure of Fluids Fig. 95. p. 6.

Pressure of Fluids Fig. 96. p. 9.



Pressure of Fluids Fig. 97. p. 9.



There is a great reſemblance between the properties of convex lenſes and concave mirrors, and between the properties of concave lenſes and convex mirrors. Convex lenſes and concave mirrors do, in general, form an inverted focal image, by the convergence of the pencils of rays: concave lenſes and convex mirrors do, in general, form an erect image in the virtual focus, by the divergence of the pencils of rays. In thoſe inſtruments whoſe performances are the effects of reflection, the concave mirror is ſubſtituted in the place of the convex lens, and the convex mirror may be uſed inſtead of the concave lens: but their diſpoſitions with reſpect to each other, when combined, muſt neceſſarily differ from thoſe of lenſes, on account of the opacity of the one and the tranſparency of the other.

Let AR (fig. 89.) repreſent the poliſhed ſpherical ſurface of a concave mirror, and OB an object ſituated without the center of the mirror; then the pencil of rays which is emitted from the point O will incide on the mirror, and after reflection converge to the focus I; the pencil from B will converge to M, and the like will happen to thoſe emit-

ted from the intermediate points, whoſe foci will be found between I and M. There will conſequently be formed before the mirror a focal image, reſembling that which is formed by a convex lens.

Let AR (fig. 90.) repreſent the poliſhed ſpherical ſurface of a convex mirror, and OB an object: then the pencil of rays which is emitted from the point O will incide on the mirror, and after reflection diverge from the virtual focus I; the pencil from B will emerge from M, and the like will happen to thoſe emitted from the intermediate points, whoſe virtual foci will be found between I and M. There will conſequently be formed behind the mirror an erect focal image, reſembling that which is formed by a concave lens.

Let AR (fig. 91.) repreſent a concave mirror, whoſe center is C, and OB an object ſituated without the center. Through the center C, from O, draw the line ON, which will be perpendicular to the mirror at N, and will therefore repreſent both the incident and reflected ray, which proceeds from O and is reflected at N: the focal repreſentation or image of O will conſequently

quently be found in that line. Through C, from B, draw the line BV, and by the ſame reaſoning the focal image of B will be found in that line. Draw the line or ray OV, and it will be reflected ſo as to croſs the ray ON at I, the angle of reflection IVC being equal to the angle of incidence OVC. This interſection of the rays determines the focal point of O, which is I. From B to N draw the ray BN, and its reflection will determine the focus of B, which is M, and the image will be inverted.

Let AR (fig. 92.) repreſent a convex mirror, and the other repreſentations and conſtruction be as in the laſt figure. The focal repreſentations of O and B will be found in the lines OC and BC, and the reflected part of the ray OV will virtually croſs the line OC at I; the reflected part of the ray BN will alſo virtually croſs the line BC at M. Theſe interſections will determine the place of the focal image IM, which will be erect.

Hence it appears to be the property of theſe mirrors, that the object and the image, if viewed from the center of the ſphere, are ſeen under equal angles; for, the angle OCB

is

is equal to the angle ICM; and that the object and image, if viewed from the point of reflection, are ſeen under equal angles; for, the angle OVB is equal to the angle IVM. From this it is eaſy to find the poſition and magnitude of the focal image, if the poſition and magnitude of the object, and the diameter of the ſphere of which the mirror is a part, be known.

The reflecting teleſcope which was made by Sir Iſaac Newton was of the following form.

Let DEFG (fig. 93.) repreſent a tube, at one end of which is placed the concave mirror AR, and let OB repreſent a diſtant object; then the pencils, which emanate from the ſeveral points of its ſurface, will be collected, and form an inverted image i m. But by the interpoſition of the plane mirror KC, the rays are reflected, and the image is formed at IM, which is ſeen very much magnified by means of the plano-convex lens at L.

The reflecting teleſcope, which is moſt in uſe at preſent, is compoſed of two concave mirrors of different radii. The larger concave

AR

AR (fig. 94.) forms the focal image IM, which ſerves as an object for the ſmall mirror KC: a ſecond image im is formed by the mirror, the rays paſſing through the amplifying lens L, which is placed in a hole or perforation in the center of the great mirror AR. This image is erect, and is viewed much enlarged through the eye-glaſs or lens P.

Reflecting microſcopes are alſo made, the method of conſtructing which, as alſo of other inſtruments, may eaſily be deduced from what has been ſaid.

The End of the First Volume.

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